Doctoral Thesis

Planning cities for the post-carbon age:
A metabolic analysis of the urban form

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ILLUSTRATIONS AUTHORSHIP

There are over 400 illustrations in this thesis. All of them are duly acknowledged.
Those without an explicit citation (over 250) have been composed by the author of the thesis.

DECLARATION

“I certify that the contents of this document are entirely my own work and that any quotation or paraphrase from the published or unpublished work of others is duly acknowledged.”

Signature(s): Date: December 20th, 2013

RESUMEN BREVE

El siglo veinte ha sido la edad de las ciudades, en la cual han experimentado la mayor expansión de su historia. La concentración de personas y actividades ha permitido un avance tecnológico sin precedentes, una larga etapa de prosperidad económica y el desarrollo de la actividad cultural. Cada día, miles de personas emigran desde sus hogares rurales en busca de las oportunidades que ofrece la metrópolis. Sin embargo, el triunfo de la ciudad ha sido a costa de la degradación de otros parajes, externos a ella, ya que absorben recursos desde distancias cada vez más lejanas. Las ciudades han crecido como sistemas voraces, basadas en el consumismo, por lo que requieren un suministro constante de materiales, agua, alimentos y energía para sostener su actividad y economía. Como tema central de investigación, las ciudades han sido estudiadas desde casi todas las perspectivas posibles. Algunas investigaciones previas han propuesto una analogía ecológica para medir los flujos del sistema urbano, lo que supone entender la ciudad como un ecosistema con un metabolismo característico. Este sería un primer paso para discernir las variables espaciales que influyen en el consumo urbano de recursos externos. Sin embargo, estos estudios todavía no han podido establecer de forma inequívoca la conexión entre la estructura física de la ciudad y su comportamiento ambiental. La abstracción de los postulados teóricos y las interferencias de múltiples factores en el análisis empírico han limitado el número de certezas en la ciencia urbana. El objetivo de esta tesis es explorar los vínculos entre forma urbana y los patrones de demanda de energía, mediante la combinación de la capacidad de exploración de modelos teóricos con el pragmatismo derivado del estudio de casos reales. Para ello, se ha elaborado un modelo de evaluación energética a escala urbana, tratando de responder a la carencia de instrumentos específicos que permitan integrar análisis y el diseño. Esta aplicación se prueba y aplica en diferentes escenarios derivados de los casos de estudios. Las experiencias de regeneración en los Docklands de Londres y el Poblenou de Barcelona proporcionan un marco real para entender la lógica de las transformaciones morfológicas en las ciudades existentes, introduciendo nuevas variables y aspectos, aunque manteniendo el foco principal de la investigación en la relación entre energía y forma urbana.

RESUMO BREVE

O século vinte foi a era das cidades, na cal experimentaron a maior expansión da súa historia. A concentración de persoas e actividades permitiu un avance tecnolóxico sen precedentes, unha longa etapa de prosperidade económica e o desenvolvemento da actividade cultural. Cada día, miles de persoas emigran dende os seus fogares rurais, en busca das oportunidades que ofrece a metrópole. Non obstante, o triunfo da cidade produciuse a custa da degradación ambiental doutros paraxes, externos a ela, xa que absorben recursos dende distancias cada vez máis afastadas. As cidades creceron como sistemas voraces, baseadas no consumismo, e requiren un fluxo constante de bens, auga, alimentos e enerxía para soster as súas actividades e a súa economía. Como tema central de investigación, as cidades foron analizadas dende case todas as perspectivas posibles. Algunhas investigacións previas propuxeron unha analoxía ecolóxica para medir os fluxos do sistema urbano, o que supuso entender a cidade coma un ecosistema cun metabolismo característico. Este sería un primeiro paso para discernir as variables espaciais que inflúen no consumo urbano de recursos. Non obstante, estes intentos de establecer unha conexión entre o comportamento das cidades e a súa estrutura física non son aínda concluíntes. A abstracción dos postulados teóricos e as interferencias de múltiples factores na análise empírica limitaron o número de certezas na ciencia urbana. O obxectivo desta tese é explorar os vínculos entre a forma urbana e os patróns de demanda de enerxía mediante a combinación da capacidade de exploración dos modelos teóricos coas aprendizaxes derivadas do estudio de casos reais. Elabórase un modelo de análise enerxético urbano para responder á carencia de instrumentos específicos de planificación que permitan integrar a análise e o deseño. Esta aplicación próbase e aplícase en diferentes escenarios de forma urbana derivados dos casos de estudos. As experiencias de rexeneración nos Docklands de Londres e o Poblenou de Barcelona proporcionan un marco real para entender a lóxica das transformacións morfolóxicas nas cidades existentes, introducindo novas variables e aspectos máis amplos, ainda que mantendo o foco principal da investigación na relación entre enerxía e forma urbana.

ABSTRACT

The 20th century has been the age of cities, as they have experienced their greatest expansion over history. The concentration of people and activities has enabled unprecedented technological advance, economic prosperity and the enhancement of culture. Thousands of people move every day from their rural homes, looking for the opportunities provided in the metropolis. However, the triumph of the city has been achieved at the expense of external environments, as they draw to themselves resources from further and further distances. Cities have grown as voracious systems, highly based on consumerism thus requiring massive flows of goods, water, food and energy to sustain their activities. As a central field of research, cities have been studied from all possible perspectives. Previous investigations have proposed an ecological analogy to measure the flows of the urban system, understanding the city as an ecosystem with a characteristic metabolism. It was meant as a first step to discern the spatial variables that influence urban consumption patterns. Nevertheless, these attempts to establish a connection between the performance of cities and their physical structure have been inconclusive so far. The abstraction of theoretical postulates and the interferences of multiple factors in empirical observations have limited the number of certainties in current urban science. The aim of this thesis is to explore the links between the urban form and energy demand patterns by combining the exploratory capacity of theoretical models with the learning outcomes from real case studies. As new planning instruments are needed to integrate analysis into design, an urban energy mode and tool has been worked out. The application was then tested and applied on alternative urban form scenarios, derived from the case studies. The regeneration experiences in London Docklands and Barcelona Poblenou provide a framework to understand the logic of morphological transformations in existing cities, introducing further variables and broader issues while keeping the control on the primary focus of the investigation: the relation between energy and urban form.

PROLOGUE

The primary focus on this investigation is to explore the potential of urban form to influence the energy demand in cities and, moreover, to discern how current development trends can be used to enhance urban sustainability. It presumes that further planning instruments need to be developed in order to meet the targets of the sustainable agenda and it will add some connotations to the prevailing theories on high density urban living. It is understood that the effectiveness of conventional measures can be greatly improved if the interventions are tailored to the specific characteristics of each situation. The research hypothesis implies a challenge on some well established conceptions and a revision of standard planning methods. Although the energy approach is a major element in the investigation, it is only a partial view on a complex issue that might lead to deterministic conclusions. The post-industrial urban forces are incorporated by the analysis of case studies, which provide a realistic background while preventing excessive digression. The starting point of the investigation could be synthesized in an opening question that addresses the most widely spread theory of urban sustainability.

“Is the compact city the most sustainable urban form for current and future cities?”

The three main issues implied by this question will structure the subsequent research. However, before any answer could be obtained, a clear definition of those concepts was required; this gave rise to further interrogations:

Regarding Urban Processes and Form:

- What defines a compact city?
- What benefits does it offer?
- What other urban forms can be found in the contemporary city?
- How can they be defined?
- Why are urban form classifications relevant?
- Is there any connection between urban form and other spheres of urban activity?

Regarding Sustainable Development and Urban Metabolism:

- What is a sustainable city?
- Which are the performance dimensions that characterize it?
- Which are the main advantages of urban compaction in the sustainable framework?
- How are energy patterns related to urban form?

Regarding Morphological Transformations in Post-Industrial cities

- What do compaction and densification processes involve?
- Which are the social implications?
- What planning instruments are available?

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ACRONYMS

AHF: Auxiliary Heating Fraction
BRE: Building Research Establishment
CASA: Centre of Advanced Spatial Analysis
CBD: Central Business District
CEC: Commission of the European Communities
CMB: Corporación Metropolitana de Barcelona
DEM: Digital Elevation Model
DJC: Docklands Joint Committee
DLR: Docklands Light Railway
ESDP: European Spatial Development Perspective
EZ: Enterprise Zone
FSI: Floor Space Index
GATCPAC: Grupo de Arquitectos y Técnicos Catalanes para la Promoción de la Arquitectura Contemporánea
GDP: Gross Domestic Product
GIS: Geographic Information Systems
GLA: Greater London Authority
GLC: Greater London Council
GLR: Gains-to-Loss Ratio
GSI: Ground Space Index
GUI: Graphic User Interface
HLC: Heat Loss Coefficient
ICTs: Information and Communication Technologies
IPCC: Intergovernmental Panel on Climate Change
KPI: Key Performance Indicators
LCC: London County Council
LDDC: London Docklands Development Corporation
LDST: London Docklands Strategic Plan
LSE: London School of Economics
LTGDC: London Thames Gateway Development Corporation
LUB: Laboratorio de Urbanismo de Barcelona
LUTI: Land Use Transportation Interaction (models)
MFA: Material Flow Accounting
MIT: Massachusetts Institute of Technology
NEPA: National Environmental Protection Act
NISA: Nova Icària Sociedad Anónima
OCDE: Organisation for Economic Co-operation and Development
PERI: Plan Especial de Reforma Interior
PGM: Plan General Metropolitano
PLA: Port of London Authority
RPAA: Regional Planning Association of America
TOD: Transit Oriented Developments
TTGDC: Thurrock Thames Gateway Development Corporation
UCL: University College London
UDCs: Urban Development Corporations
UEI: Urban Energy Index
UHI: Urban Heat Island
UNEP: United Nations Environment Program
VMT: Vehicle Miles Travelled
VOC: Volatile Organic Components
VOSA: Villa Olímpica Sociedad Anónima
WMO: World Meteorology Organization
WWII: World War II

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CHAPTER 1

INTRODUCTION

1.1 The context

The last four generations have witnessed an unprecedented urban growth. The dimension of the urbanized territory in the last sixty years has surpassed the previous five thousand. A symbolic landmark was reached one decade ago, when it was estimated that there were more urban than rural habitants for the first time ever. This urban revolution was induced by a series of scientific discoveries that enabled successive waves of industrialization which, in turn, attracted massive flows of workers from rural areas to manufacturing and trading hubs. Cities liberated peasants from the rigours of rural servitude, offering them the opportunities of civilization. Cities were berth for culture, art, education, scientific endeavour and economic production. The great scientific achievements that enabled the eradication of mortal diseases, the prediction and prevention of natural disasters or the generalization of leisure were possible thanks to the concentration and interaction of people in the urban milieus. Despite the shift in the notion of proximity brought about by new communication technologies, cities are still poles of attraction for people seeking opportunities and prosperity. Indeed, the progressive mechanization of labour in the primary and secondary sectors has reinforced the role of a new kind of tertiary that is strongly based on socialization and networking which are, again, enhanced by urban environments.

But cities also concentrate the downsides of human action. Slums and shanty towns surround many of the largest cities in the world. Pollution, biodiversity, crime, and illnesses (lung cancer, stress...) are worsened by the effects of urbanization and related activities. Moreover, urban dwellers are strongly dependant on external resources, as their autonomy to produce even the most basic goods is very limited. They lack the ability of rural habitants to grow their own food or to obtain raw materials at little or no cost. The logistics to supply food, water, energy and other goods to fulfil the needs of the urban population requires a complex organization that involves extraction, transportation and distribution to the points of consumption and, finally, the collection and disposal of waste on landfills or treatment plants. These processes affect areas that are external to cities, which draw to themselves resources from longer and longer distances. The environmental degradation of those areas is proportional to the size and wealth of the population they serve. As cities have grown as centres of commercial exchange, they get richer as the flows of materials, energy or food increase. This vicious cycle is, therefore, fed by a cannibalistic instinct that is inherent to the urban economy. This voracity was not too disturbing when cities were exceptions in predominantly rural societies or, later, when the gap between the first world and third world compensated the overconsumption of the former with the frugality of the later. However, emerging countries, which are geographically located in some of the most densely populated areas of the world, have engaged a burst of rapid urbanization, reverting poor and rural peoples into urban consumers in less than a decade.

It has been estimated that cities consume about 60-80% of the world's energy and are responsible of 80% of the CO_2 emissions[1]. With developing countries engaging consumerism, all evidences seem to indicate that a greater pressure upon natural and energy resources will be exerted. Moreover, 80% of the energy comes from fossil sources[2], whose exhaustion is estimated within the next generation[3]. In this scenario, planning future of cities for a post-carbon context seems an ineluctable duty that permits no further delay, as the structures that we build today will be inherited by the generations to follow.

1.2 The supply side of the energy problem

Renewable technologies are being explored to replace conventional energy sources. Wind and solar are presented as promising alternatives as they are widely available. Their annual yield has increased an average of 30% in the last years[4]. According to Nobel Prize Walter Kohn, the current levels of energy demand could be met by wind and solar in two or three decades if this growing rate were sustained. Obviously, he highlights, this is a big if, an overoptimistic assumption that contradicts the current scenario of research funding being cut down.

Hydropower is a long established renewable that supplies about 6% of global energy or some 15% of the world's electricity[5]. The main problem to extend the use of this

1 Burdett & Rhode, 2012 Marr & Wehner, 2012
2 Nakicenovic, 2010
3 Estimation of global reserves for Oil: 25 years Natural Gas: 40 years Coal: 200 years (Edwards, 2010)
4 Kohn, 2010
5 Roaf, Crichton & Nicol, 2009

technology is the opposition to new dams from local residents and environmental groups. Moreover, it is very dependent on weather conditions as both floods and droughts can strongly affect its operation. Newer low carbon alternatives have been explored in the last decades, including geothermal, tidal, wave, biomass, combined heat and power and smart grids to maximize efficiency. All these technologies have two things in common: they are characterized by a relatively low spatial power density and they focus on the supply side. It has a direct impact in planning, as large areas of land have to be designated for this purpose. Planning teams will need to analyze the systems that are suitable for each case, where they should located to have a minimum impact and the measures to mitigate their environmental impact.

1.3 The demand side of the problem

The difficult implementation of renewable energy sources and their anticipated inability to match current supply levels calls for a deeper consideration of the demand side. The delusion of secured short term supply has generated a certain complacency that prevents improvements at user level. The global energy consumption increases continuously despite evidences calling for the need of adaptation. Buildings and cities that are being currently designed will be impossible to run without a huge energy input, and they will soon become unaffordable.

The approach to energy efficiency from the demand side involves three stages:

- **The analysis of demand patterns.** The understanding of the factors that generate the demand is the first step to indentify priorities and evaluate potential strategies. In a global dimension, buildings, transportation and industrial activities (including energy generation) concentrate most of the energy demand, accounting for about one third of the demand each. A more detailed dissection reveals domestic buildings as the largest single consumer in most European countries. It represents over 40% of the total energy demand in UK, Germany or France, and nearly 30% in Mediterranean countries such as Spain, Italy or Greece. The energy of households is used, primarily, for space heating and lighting. In the UK, domestic space heating alone represents 20% of the national energy usage.
- **Design and prescription of strategies to modify demand patterns**. It has been stated that about 70% of delivered energy is arguably influenced by planning[6]. The way in which cities and buildings are designed has an enormous impact on the future dependence on conventional fuel sources. Passive strategies have been successfully devised to improve buildings' performance. Solar heating, proper insulation and ventilation control have helped to increase the energy efficiency of domestic buildings by a factor of two in the last thirty years. A number of prototype projects have, moreover, demonstrated the potential to deliver carbon neutral buildings through a combination of robust design and onsite energy generation. At urban level, there are few certainties, as most of the knowledge is based on theories that can be hardly tested or prototyped.

  Current mainstream theories postulate density, compactness and mix of uses as the constituents of urban energy efficiency. These claims are based on two fundamental assumptions, which are frequently associated to this model: firstly, compactness reduces the need for travel and, secondly, energy conservation in buildings is enhanced when cities develop vertically instead of horizontally.
- **Implementation of policies and strategies.** The creation of agendas to generalize measures of energy efficiency has been usually promoted by governments and public administrations. In Europe, international agreements, statutory directives and advisory documents create a common framework that has to be transposed to the different member states. The EPBD[7] and its amendments set ambitious targets for the energy performance of buildings. New constructions will be required to become "nearly zero energy" in a relatively short term. Regarding cities, advisory documents are abundant but not mandatory. The Green Paper on the Urban Environment[8] proposed targets for "urban environment improvement" that included policies to reduce "the impact of urban activities on the environment" by means of efficient "urban energy management". It listed a number of areas of action that were to be evolved by the member states and then incorporated into national town planning codes. Urban transport and buildings' energy efficiency were two of these areas. They were defined by general principles such as the encouragement of public transportation or the energy conservation in buildings. Although some states (e.g. Spain) developed detailed guidelines based on those principles, they were neither mandatory nor were they applied by planning agencies. It can be alleged that the overproduction of technocratic papers about urban enery efficiency did not deliver susbtantial results in practice.

Although knowledge on urban energy has been highly developed, the biggest incentives have focused on the supply side so far. Alternative technologies and sophisticated systems have been engineered to improve the efficiency of energy generation and to find solutions to the predicted fuel

6 Owens ,1992 and Williams et al, 2000

7 Energy Performance of Buildings Directive 2010/31/EU

8 CEC, 1990

shortage. Electric cars, smart grids and on site renewable energy systems have been widely explored and can be readily available for general use in a short term. In addition, recent methods for data collection, processing and analysis have opened new opportunities to understand urban processes, also those regarding energy demand. However, the transformation of this vast amount of information into useful and feasible planning instruments has not progressed at the same speed. The overreliance on building insulation has minimized the interest on further design improvements while density is seen as the panacea to reduce the need for travel. Consequently, deterministic prescriptions are being enforced for general application without considering the specificity of each case. At best, building codes determine minimum insulation thresholds for each climatic zone, leading to a disregard of other factors, such as user's interaction, building form and, particularly, the immediate urban context. Similarly, fondness for density has spread from north to south and west to east. Both London and Barcelona aim for it, while they start from opposite poles as being paradigms of extensive and intensive forms of urban development.

1.4 Research objectives

The primary focus of this investigation is to explore the potential of urban form to influence the energy demand in cities and how current development trends can be used to enhance urban sustainability. It presumes that further planning instruments need to be developed in order to meet the targets of the sustainable agenda. It is understood that the effectiveness of conventional measures can be greatly enhanced if the interventions are tailored to the specific characteristics of each situation. The research hypothesis implies a challenge on some well established conceptions and a revision of standard planning methods. Prevailing theories on high density urban living will be crtitically revised . Although the energy approach is a major element in the investigation, it would be a partial view of a complex issue, which may lead to deterministic conclusions. The post-industrial broader context is incorporated in the thesis by the analysis of case studies, which provide a realistic background while preventing excessive digression. The starting point of the investigation is synthesized in an opening question that retrieves a central line in the debate on urban sustainability:

- **"Is the compact city the most sustainable urban form for current and future cities?"**

The three main topics (urban form, sustainability and evolution) implied in this question will structure the subsequent research. However, before any answer could be obtained, a clear definition of those concepts was required. This gave rise to further interrogations:

- **Regarding Urban Processes and Form:**
  - What defines a compact city?
  - What benefits does it offer?
  - What other urban forms can be found in the contemporary city?
  - How can they be defined?
  - Why are urban form classifications relevant?
  - Is there any connection between urban form and other spheres of urban activity?
- **Regarding Sustainable Development and Urban Metabolism:**
  - What is a sustainable city?
  - Which are the performance dimensions that characterize it?
  - Which are the main advantages of urban compaction in the sustainable framework?
  - Finally, how are energy patterns related to urban form?
- **Regarding Morphological Transformations in Post-Industrial cities**
  - What does compaction or densification processes involve?
  - Which are the social implications?
  - Which planning instruments are available?

1.5 Thesis structure

The thesis document has been arranged in three different levels. Firstly, the general level divides the contents in two parts: the first one is more theoretical and the second part is more practical. The second level contains four sections, two in each part, and, finally, the smaller level includes the ten chapters (without introduction and conclusions). The chapters do not follow a rigid linear structure but, at contrary, can be read in alternative sequence without disrupting the main lines of the argumentation. Each chapter is rather autonomous: They include a thorough description on each subtopic, with a critical study of precedents, analytic work and a brief conclusion, summarizing the main insights.

The text is complemented with abundant graphic material. Drawings and diagrams are both analytic and illustrative, although their main role is to facilitate the comprehension of the logical arguments. The whole thesis contains over 400 figures. Around 70% of them have been composed by the author as part of his research analysis.

The general structure of the thesis is described in the following table:

- Part 1: Theoretical Background. The first part reviews the main concepts that will be addressed along the thesis, in particular, urban form and sustainability. This is a critical review, in which precedents are analysed, challenged and tested. Although primarily theoretical, it includes a substantial amount of analytic work as to provide original insights in each topic. Urban Morphology is underlying in every chapter as the aspects of performance are studied in relation to it.

Section 1: Context and Fundamental Principles. This section starts from a definition of cities and urban form to set the general framework. The following chapters move on from the general notion of Sustainability as the current consensus, to specific issues, such as the energy performance of buildings and travel. These chapters implied a vast bibliographic review to compile the different views with their arguments and evidences on each topic.

Chapter 1: Introduction

Chapter 2: The Study of Urban Morphology. One of the objections that can be laid on previous studies about sustainable city form is the consistent neglect of classic theories of urban morphology. Instead of making a new definition up from scratch, this chapter presents a review of classic references that informs and inspires a synthetic classification of urban form. The reasons why typifying cities is relevant are explained in the initial paragraphs.

The study of the form was approached for different purposes and from different angles and scales: from German geographers such as Von Thünen and Christaller, who focused on economics and land use patterns to the interpretation of cities as networks of flows, which can be remotely sensed, mapped and analyzed. The final paragraphs are devoted to introduce the connection between form and performance. This is illustrated by the analysis and classification of twenty six European regions. New measures of compactness and mixture are put forward after their spatial analysis. London, Brussels and Cologne are characterized by their extensive and monofunctional forms of urban growth. They are the antithesis of the compact city, which is better represented by Barcelona, Madrid or Lisbon. The connection between this definition of urban form and key performance indicators prepares the ground for a deeper discussion on qualitative assessment, which is the starting point of the following chapter.

Chapter 3: Sustainable City Paradigm as a Matter of Form. This chapter aims to produce unambiguous criteria to define good urban performance based on the objective interpretation of current collective targets. It consists on a purely theoretical reflexion on how the criteria to define the goals of city planning have shifted in each historic context, since the emergence of modern town planning to the present paradigm. The retrospective study begins with the urban explosion that came after the industrial revolution, whose harmful consequences on the working class gave rise to an environmental conscience of philanthropic inspiration. Eventually, it led to the enforcement of the earliest planning codes, which incorporated hygienist measures to improve ventilation and daylight conditions in the urban environment. A different order of priorities emerged after in the post-war of WWII, partly due to the need for reconstruction and partly due to the improvements that had been achieved thanks to the previous reforms. In this case, the focus was on the natural environment. The society became aware of the impact of human activities after a series of disasters received wide media coverage. The social pressure compelled governments to enforce specific assessments about the impact on the environment as a mandatory part of urban development and industrial activities. The preservation of natural habitats and the mitigation of disruptions on ecological systems became characteristic objectives during this second wave.

The crisis in western manufacturing industries, whose decline had begun in the ninety sixties, brought massive unemployment to the core of cities and inspired a new agenda in the welfare state: the sustainable development. The social and environmental concerns that were raised in the previous cycles were now complemented with the economic objectives, to complete the triangle of needs of the sustainable agenda. The current good city form is, therefore, determined by the fulfilment of these needs for present and future generations.

Chapter 4: Buildings' Energy and Urban Form. The notion of sustained satisfaction of human needs implies the quantification of available resources and the balance between consumption and regeneration rates. The ecological analogy, which compared cities with ecosystems, has been used to create a systematic method to evaluate the flows that sustain urban activities, including energy, food and water. These flows should be kept within the carrying capacity of the system to ensure its sustainability. However, this is rarely the case in developed societies, as cities are open systems that draw resources from external environments. Urban metabolic studies were regularly undertaken since Abel Wolman applied this method to an imaginary American city[9], estimating the water, energy and food were required to feed the urban system. Later nergy flow analysis would confirm transport and buildings as the consumers of about two thirds of urban energy.

This chapter focuses on the variables of urban morphology that influence the energy performance of buildings. The correlations between form and performance need to be established in order to be able to predict the effect of planning proposals on urban metabolism. There are two ways in which building efficiency is affected by urban morphology:

-The first level has to do with the relative position of the building in the city and the urban climatology. The overall form of the city generates different microclimates, which can induce thermal variations up to 10K in relatively near zones. It has been established that urban geometry, as well as weather conditions, have a strong influence on the occurrence and intensity of this phenomenon, known as urban heat island

9 Wolman, 1965

effect[10] (UHI). The dynamics of the UHI are thoroughly explored and illustrated in six European cities. The potential impact of the UHI in energy consumption patterns is then analyzed for London and Barcelona, showing how the same building, placed in different locations within the same city presents a different performance.

-The second connection between urban form and building performance consists on the symbiosis between buildings and their immediate surroundings. According to Baker & Steemers[11], the urban setting can induce twofold variations in buildings' energy. Dense environments can prevent solar access and adequate ventilation whereas low rise typologies are more exposed and may have greater heat losses. The aspects that determine building performance are analyzed in relation to urban parameters. A synthetic matrix summarizes all the connections, stating the existence of a correlation, its strength and whether it is positive or negative.

Chapter 5: Urban Form and the Impact of Travel. In this chapter, the focus moves to the analysis of mobility and its connection with the spatial structure of the city, as the second most important factor in urban metabolism. It starts from an introduction to the fundamental principles and concepts of urban travel patterns. The classic transportation models, their methods and elements are then discussed in detail. The second part focuses on the implications of urban morphology, a topic that has been profusely studied but remains highly controversial. Density has been frequently identified as a moderator of the need for travel, especially after Newman and Kenworthy's worldwide survey[12]. Arguments and evidences for and against this theory are presented, and critically analyzed in this chapter. Finally, a meta-analysis compares the results from a selection of transport studies conducted in European cities. The most consistent connections are plotted in a synthetic matrix, portraying the correspondence between factors, the strength of the correlations and the negative or positive impact.

Section 2: Analysis and Application. The second section of the first part responds to a gap identified in the current planning toolbox. This investigation requires of instruments to evaluate energy performance at urban scale. However, proper tools were either inexistent or unavailable. At the moment of writing this document some were being developed, but any of them was found appropriate to account for formal variations in citywide analysis. The solution was to develop an original model and tool to produce energy performance assessments in large urban areas, based on characteristic planning parameters.

Chapter 6: An Urban Form Energy Analysis and Model. This chapter reports on the conception and development of an urban energy index (UEI) model to perform rapid estimates for heating, lighting and cooling loads in five building types (domestic, retail, office, industrial, facilities) based on the analysis of urban morphology. The concept of the model assumes that there is a sound knowledge on the effects of building elements, such as window ratio or insulation levels, so that the focus was laid on urban parameters. It implies that many assumptions had to be taken at building level. The chapter starts from a detailed analysis of the antecedents that inspired the model. Ease of use and speed in computation were fundamental objectives. Having a sound structure and a reduced number of parameters facilitated the control and legibility of background operations. Urban Energy Index uses Floor Space Index (FSI) and Ground Space Index (GSI), together with building compactness, as main input parameters. The hypothesis to build the model presumed that the combination of those variables contained enough information to make meaningful estimates of energy performance on large urban areas.

A discussion on the theoretical context and the connections with classic urban morphology precedes the description of the model's parameters, which are divided in: basic parameters (FSI, GSI and Compactness Ratio), default parameters (orientation, floor height, glazing ratio, construction type, thermal capacity and albedo) and context parameters (climate zone, latitude, orientation of prevailing urban axes, land use and building type). The mathematical model and the physic principles involved in the calculations are explained in the following pages. The key step in this methodology was the simplification of the urban fabric, which is reduced to a notional grid that retains its characteristic urban parameters. The preservation of those values, which is fundamental to perform meaningful estimates, is demonstrated by mathematical relations.

The test and validation of the model was a lengthy process that involved over two thousand observations. Twenty eight urban samples were selected from five European cities, of different climatic zones (Madrid, Barcelona, Paris, London and Berlin). Climatelite was used as reference tool. It is based on the LT model, which is embedded into a graphic user interface that allows to draw the urban geometry as in a CAD tool. The validation consisted on three steps:

-Firstly, the effectiveness of the notional grid to represent urban form was assessed.

-Secondly, the UEI was compared against results from simplified Climatelite models (i.e. the notional grid was modelled in Climatelite).

-The final test consisted on the comparison between UEI and the results from detailed model in Climatelite (i.e. the urban geometry, building by building).

10 Oke, 1987

11 Baker & Steemers, 2000

12 Newman & Kenworthy, 1989

Results showed an overall correlation of $r^2=0.75$, with a stronger correspondence for domestic types and heating loads, while weaker values were shown for lighting and other uses (retail or office).

The second part of this chapter takes on the results of the validation process to perform a typological and parametric analysis of the urban form. The objective was twofold: to evaluate the influence of FSI, GSI and compactness in energy demand from buildings and to test the applicability of the tool. One of the findings was the liability of parametric analysis to produce misleading results. When urban parameters are assessed individually, all parameters but the one assessed are kept constant. However, this is not normally the case in reality, as some parameters are, indeed, correlated. This is discussed and explained with examples. The conclusion will demonstrate that typological analysis presents a better description of real energy patterns.

As the results from the parametric analysis were rather inconclusive, the tool was developed in three formats, as to facilitate bespoke assessments. Potential users could find the fittest format for each situation:

- Spreadsheet format, which provides the most accurate results while allowing a great flexibility.
- Regional diagrams, in which energy can be calculated by simply intersecting values of FSI and GSI or Compactness in a graph
- A GIS integrated model was created to extend the capabilities of the tool, improve the visualization and facilitate the automatic measurement of input parameters.

- Part 2: Applied Research. The second part of the thesis takes a practical approach. After the theoretical aspects and concepts were clarified, this part of the discussion moves on to the analysis of real case studies. London and Barcelona were selected for the following reasons:

- They are examples of opposite urban forms: compactness and dispersion. This was used to test the correspondece between energy patterns and the spatial structure. A research hypothesis stated that densification would have a stronger potential in London than in Barcelona as the latter has a higher density and little scope for further compaction.
- Both cities have undertaken important regeneration projects in central areas that implied a partial transformation of their urban form. It provides a real framework to an otherwise abstract debate. The difficulties and consequences from densification are exemplified by the two cases.
- There is abundant data on the cities and the regenerated districts. It facilitates objective analysis on the effects of the transformations and to crosscheck data with various sources.
- None of the case studies has been highlighted as a sustainable prototype. However, this is seen as a positive value as, on the one hand it allows a clean view without distortions of sustainable claims. On the other hand, learning outcomes extracted from regular planning experiences are easier to implement than the lessons from exceptional projects that respond to very specific conditions.

Section 3: Case Studies. The first section of the second part analyzes the urban evolution of the case studies and their recent transformations. Every period is associated to a characteristic urban form, both in its region and its fabric. The metropolitan evolution is portrayed in maps that highlight the historic advance of urbanization. The intra-urban transformations are identified by the traces in the current fabric. Urban typologies are not spontaneous but they respond to specific decisions taken at specific moments and for specific reasons. The historic development of the urban form helps to understand the processes that induced each typology. The geography and the social and political scenario created different contexts for Barcelona and London, whose results were translated and can be read in their spatial form. The understanding of retrospective events will be used to recognize the prevailing typologies across the post-industrial city, which gives information about their performance. The analysis of urban evolution also unveils the logic of urban growth, anticipating future trends. Both cities have experienced a decentralization process and the decay of their industrial districts in the late 20th century. The regeneration of these areas antagonized prevailing urbanization patterns, turning the attention back to the city. The ups and downs of these processes are analysed as examples of the most radical transformations that are possible in the context of the European metropolis.

Chapter 7: The Formation of a Scattered City: London. This chapter explores the urban evolution of London, from the Roman period to present time. The formation of London was determined by its strategic position at the outermost crossing point of the Thames estuary. Although it hosts the Royal Court, it has been a city of merchants, a character that still stands at present time, as hub of global trade. The chapter disentangles an apparently amorphous continuum of concrete to unveil the underlying structure of London, making use of a profuse display of graphic material..

Chapter 8: Densification in a Post-Industrial Scattered City: London Docklands. The redevelopment process of the former London Docks has been one of the biggest regeneration projects in Europe. The position of London as centre of the British Empire required a large port to handle the intensive trade with the colonies. This chapter begins with the explanation of how this port acquired its past configuration, out of sheer speculation and competition, which led to its inability to adapt to technological shifts. The decay of the port swept away the livelihood of surrounding communities, which were low skilled and highly dependent on maritime activities. The transformation of Docklands, from industrial and manufacturing centre to financial and residential district had to balance the needs of the local population with the interest of acting development forces. The successive strategies to carry on the regeneration are examined in the main part of the chapter. A number of plans synthesise the spatial transformations, summarizing the key figures and the end result.

Chapter 9: A Compact City Paradigm: Barcelona. The evolution of Barcelona presents parallels and contrasts with London. Until the 18th century, the urbanization patterns are similar to many other European cities, with successive enlargements as densification within the walls became unbearable. At the beginning of the 18th century, this trend was interrupted by the military control of the city, in revenge to their support to French monarchs in the Spanish Succession War. The medieval precinct was overcrowded by the progressive densification of the built fabric. When, over a century later, the walls were finally demolished, the surrounding flat was readily available to design the city's expansion. In the mid 20th century, Cerdà's extension had reached the hills of Collserola, a geographic barrier that constrained further growth. This chapter describes the formation of Barcelona as a compact city, the reasons that led to this form and the prevailing urban typologies that emerged from it. As in the previous chapters, graphic material is instrumental in the analysis of the evolution of the urban form.

Chapter 10: Densification in a Post-Industrial Compact City: From Poblenou to 22@. Poblenou is an industrial suburb originated in the 19th century with its own urban logic that was swallowed by Cerdà's grid in the early 20th. Its growth as manufacturing area was of a poor urban quality and propitiated the creation of small slums on its periphery. This chapter dissects the different stages of the regeneration of this area, from the pre-Olympic period to present time.This process portrayed a myriad of planning instruments, concepts and strategies, which aimed to transform a consolidated part of the urban fabric, where small firms still operated, families lived and cultural events were being performed. It reports, both descriptively and analytically, the sequence of events, their logic in the broader context and the consequences in the spatial structure and local communities.

Section 4: Comparative Analysis. The final section presents the comparative metabolic analysis of London and Barcelona. It summarizes the concepts and tools developed in the thesis by their application upon the case studies. The aim is to test the research hypothesis by discerning the performance on alternative urban forms in different contexts. Highly speculative prodcedures are applied in order to provide evidences on the future evolution of the energy performance of cities.

Chapter 11: Comparative Analysis and Performance Assessment. As shown in previous chapters, the arguments to present a sustainable urban form vary from the firm defence of density to its opposite, the apology of pseudo-Arcadian rural landscapes of self-sustained communities. This chapter analyses alternative urban forms, taking the case studies as holistic references, both in terms of quantitative performance and social impacts. Only in this way, it will be possible to draw an evaluation based on objective evidences as well as on rational judgment. Essentially, the appraisal, aims to answer the following questions:

- How significant are the potential energy savings derived from urban compaction?
- What are the collateral effects of further densification in consolidated urban areas?
- Do potential benefits outweigh the negative effects?
- Are there alternatives to density and compactess that can deliver similar energy savings without affecting the urban structure?

Subsequent research combined empirical observations with speculation to explore the consequences of urban policies leading to further compactness as opposed to the continuation and enhancement of current decentralizing trends. Energy performance per capita was the key indicator to compare different scenarios. Personal travel and domestic heating load were then the specific factors whose variations would be estimated in relation with alternative spatial arrangements. The comparative analysis consisted on two stages:

-The first stage was based on the observation of existing patterns, using contrasted data and analyzing energy flows in the current urban structure of London and Barcelona

-In the second analytic stage, exploratory urban models were elaborated, using the learning outcomes from the previous phase. These models aimed to infer hypothetical scenarios for the future evolution of London and Barcelona, based on their current structure and assuming alternative degrees of compaction and sprawl. Finally, an estimate of the energy demand per capita was calculated for each scenario, using the tools and methods developed in previous chapters.

About Methodology

Antecedents and personal background. The inception of this thesis is dated on the summer of 2008. During that time I was undertaking MSc research in Sustainable Environmental Design at the Architectural Association (AASED). The disseration topic was about the environmental retrofit of urban housing in the North West of Spain. One of the conclusions from that investigation revealed the strong influence of the urban context on the environmental performance of buildings. Two existing housing blocks, of similar construction and occupation patterns, but in different urban settings were analysed, after and before they were retrofitted. While the initial behaviour was similar in both cases, the performance after the retrofit was substantially different. The building in the denser fabric was unable to achieve internal comfort conditions, while the buildings without external obstructions kept indoor temperature above 20ºC, even in cold periods. This discrepancy inspired a proposal for further work, about the influence of urban form in the energy performance of buildings.

Doctoral studies were started one year after finishing the AASED master's degree, combining research with teaching activities, both in Spain and London. The continuous contact with the foremost programmes and prominent figures in urban and environmental disciplines provided an unique opportunity to articulate a balanced interdisciplinary approach, merging technical aspects with a strong theoretical background on urbanism. However, specific skills had to be stretched in order to undertake urban analysis with the same level of confidence than environmental issues. This was sorted out by doing a five months research stay at the Bartlett Centre of Advance Spatial Analysis (CASA), a department of cutting edge urban studies of the University College London. This experience was highly productive as not only allowed me to develop the GIS applications of the investigation but it also provided valuable contacts and cartographic information that could not have been accessed otherwise.

The city as more than the result of a juxtaposition of buildings. The shift from building to the urban scale was by no means understood as a mere juxtaposition of buildings but an entirely different issue. One of the main problems detected from previous energy studies was that they tended to extrapolate the same analytic methods that were developed for buildings to large urban areas. On the one hand it created practical problems in terms of data handling and, on the other hand, it prevented a deep penetration of research in urban planning and design as they tend to use their own parameters and variables. Planners are not necessarily as familiar with terms such as U-value, heat losses or thermal inertia as they are with density or plot coverage.

Integration of planning and environmental concepts. The training and experience as architect and urbanist, together with the specialization in urban regeneration environmental design, facilitated the combination of environmental principles with urban fundaments. The research began with a thorough immersion into key urban theories that form the background of planning methods. This is reflected in the initial chapter, which dissects urban morphology from the classic schools to current theories. These studies aimed to review and understand the common methods that are being used in planning analysis and how energy aspects could be better integrated into them. In this sense, the development of the energy assessment tool had among its initial objectives to use planning variables to generate the estimates. The notional grid method was devised to synthesize most of the data that is required to perform a meaningful evaluation and then to translate it as density (Floor Space Index), and plot coverage (Ground Floor Index).

The case study method approach. The decision to complement the theoretical analysis with case studies was based on the need for empirical evidences and a specific context to inform and support the arguments. The case studies provided a real framework and abundant data that helped to manage the complexity of otherwise abstract flows. In a way, it represents a choice between the imaginary city of Abel Wolman and the metabolic studies of the late seventies, which portrayed real data from specific cities. The analysis of the case studies is not limited to data collection but it also provides information about processes, events and decisions that induced urban change. The reasons why London and Barcelona were selected have been explained above. They represent opposite urban models, in a European context and they have regenerated an important part of their central districts after the decay of their industries, which implied a densification of population and jobs. In addition, both cities are well known by the author from firsthand experience, so that access to both publicly available and restricted information could be granted.

- Tools, data and information sources. A broad range of analytic instruments were extensively used in the thesis. Responsibility, rigour and reliability were the cornerstones that guided the selection and use of external information and tools.

The following analytic tools were used throughout the thesis:

- ArcGIS 10.1
- ClimateLite 1.3.0734
- Ecotect Analysis 2011
- Energy Index
- GvSIG desktop 2.0
- Microsoft Office Excel 2007
- Modis Reprojection Tool v.4.1

- OpenStudio 0.10.0 / Energy Plus 7.2
- Sextante 1.0.9
- Urban Network Analysis v1.01 for ArcGIS 10
- In addition, the Urban Energy Index was created as part of the thesis. The model was integrated in Microsoft Office Excel 2007 and ArcGIS 10.1

The following can be highlighted as key data sources:

Transport Data:

- Ajuntament de Barcelona (2012) Dades Básiques de Mobilitat 2011. DOYMO
- Department for Transport (2013) National Travel Survey 2012. Technical Report. NatCen Social Research
- Department of Traffic (2013) Road Traffic Statistics. Online resource: available at www.gov.uk/government/organisations/department-for-transport/series/road-traffic-statistics [last visited 10.11.2013]
- Department of Transport (2002) National Travel Survey 2002. National Statistics, Department of Transport. www.dft.gov.uk/pgr/statistics/datatablespublications [last visited 29.11.2012]
- IERM (2006) EMQ 2006 de la Regió Metropolitana de Barcelona. ATM Generalitat de Catalunya. Departament de Política Terriorial i Obres Públiques
- ONS (2003) Borough Commuting Patterns. Census 2001 Special Workplace Statistics Table SWS103. Online resource available at data.london.gov.uk/datastore/package/borough-commuting-patterns-census-2001 [last accessed on 15.11.2013]
- ONS (2013) Area Based Analysis, Commuting Patterns from the Annual Population Survey, Local Authorities, 2010 and 2011 Online resource available at www.ons.gov.uk/ons/rel/regional-trends/area-based-analysis/commuting-patterns-from-the-annual-population-survey--local-authorities--2010-and-2011/index.html [last accessed on 15.11.2013]
- Transport for London (2010) Travel in London. Report 3. Mayor of London
-

Energy Data:

- CORES (2013) Consumos de Gasolinas, Gasóleos y Fuelóleos por Provincias y Comunidades Autónomas. Ministerio de Industria, Energía y Turismo. Online resource available at www.cores.es/esp/estadisticas/estadisticas-petroleo/consumos-Petroleo.html [last accessed on 15.11.2013]
- DECC (2011) Energy Consumption in the UK Transport Data Tables. National Statistics
- Eurostat (2009) Panorama of Energy. Energy statistics to support EU policies and solutions. European Commission
- IDAE (2011) Proyecto SECH-SPAHOUSEC. Análisis del Consumo Energético del Sector Residencial en España. Informe Final. IDAE Eurostat. Ministerio de Industria Energía y Turismo
- INEGA (2005) Balance Enerxético de Galicia. 2005 Galician Energy Institute
- UK Statistics Authority (2011) Energy Consumption in the United Kingdom. Department of Energy and Climate Change
- Utley. J.I & Shorrock, L.D. (2008) Domestic Energy Fact File 2008. BRE.Energy Saving Trust. Department of Energy and Climate Change

Cartography and general data

- Cartografía Vectorial. Dirección General del Catastro
- https://www.sedecatastro.gob.es/OVCInicio.aspx [last visited 15.12.2013]
- Catálogo de Cartografía Area Metropolitana de Barcelona
- http://cartografia.amb.cat/cartografia/?lang=es [last visited 15.12.2013]
- EDINA DIGIMAP. The most comprehensive maps and geospatial data available in UK for students, teachers and researchers in UK Higher and Further Education
- http://digimap.edina.ac.uk/digimap/home# [last visited 15.12.2013]
- European Environment Agency
- Raster data on population density using Corine Land Cover 2000 inventory
- GMES Urban Atlas
- Geoportal Barcelona
- http://w24.bcn.cat/GWMPNet61_bcn/extlayout.aspx [last visited 15.12.2013]
- Institute for Environment and Sustainability (IES)
- http://image2000.jrc.ec.europa.eu/DI/IM.htm [last visited 15.12.2013]
- Instituto Geográfico Nacional
- http://centrodedescargas.cnig.es/CentroDescargas/catalogo.do [last visited 15.12.2013]
- LANDMAP.
- http://landmap.mimas.ac.uk/ [last visited 15.12.2013]
- Observation Network for Territorial Development

and Cohesion

- http://www.espon.eu/ [last visited 05.04.2011]
- Ordinance Survey. OS Open Data
- https://www.ordnancesurvey.co.uk/opendatadownload/products.html [last visited 15.12.2013]
- Urban Audit City Profiles. Eurostat and European Commission Directorate-General Regional Policy. Online resource: www.urbanaudit.org/CityProfiles.aspx [last visited 24.10.2013]
- USGS Earth Resources Observation and Science (EROS) Center
- http://eros.usgs.gov/ [last visited 15.12.2013]

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- Baker, N. & Steemers, K. (2000) Energy and Environment in Architecture. A Technical Design Guide. E & FN Spon
- Burdett, R. & Rhode, P. (2012) The Electric City. Urban Age Electic City Conference 6-7 December London 2012. LSE Deutsche Bank's Alfred Herrhausen Society
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- Marr, M.A. & Wehner, S. (2012) Cities and Carbon Finance: A Feasibility Study on a Urban CDM. UNEP. Gwangju City
- Nakicenovic, N. (2010) Energy Research and Technology for a Transition Toward a More Sustainable Future. In Schellnhuber, H.J. Molina, M. Stern, N. Huber, V. Kadner, S. (2010) Global Sustainability. A Noble Cause. Cambridge
- Newman, P. & Kenworthy, J. (1989) Cities and Automobile Dependence: An international Sourcebook. Gower
- Oke, T.R. (1987). Boundary Layer Climates. Methuen & Co., London
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- Roaf, S. Crichton, D. & Nicol, F. (2009) Adapting Buildings and Cities for Climate Change. A 21st Century Survival Guide. Elsevier
- Williams, K. Burton, E. Jenks, M. eds. (2000) Achieving Sustainable Urban Form. E&F N Spon
- Wolman, 1965 Wolman, A. (1965) The metabolism of cities. Scientific American, 213 N. 3 pp-179-190

CHAPTER 2

THE STUDY OF URBAN MORPHOLOGY

2.1 Reasons to study the urban form

The study of city form has been a classic field of urban research, to the extent that it became a distinctive theoretical discipline during the second half of the 20th century. The timeline of urban morphology may include a myriad of approaches and heterogeneous referents, from Vitrubius' ideal city to Muratori's typological analysis, or even the incorporeal '*city of flows'* portrayed, among others, by William Mitchell or Manuel Castells. Despite this broad range of visions, which differ in the scale and scope of their postulates, they all tackle aspects of urban form with a common aim: to gain a better understanding of the intrinsic nature of cities. It also suggests a certain ambiguity in the conceptual definition of the urban form. The term has, indeed, evolved and mutated along the city, making necessary to furnish any dissertation on the topic with an explanatory prelude[1] to clearly state the particular approach that is being taken. ***Urban form*** may be intuitively interpreted to the way in which the city is observed, its visual manifestation. It can be thus defined by its skyline[2], or by the silhouette that emerges in contrast to a natural background as seen from a hill, or by the amorphous continuum of roads and buildings as perceived from within. The visual characterization of the city was a mainstream approach until the mid 1960s, when non spatial issues were revealed as fundamental elements of urban systems. Batty and Longley pointed out[3] that *the form of an object is a diagram of forces*[4] and therefore, any meaningful study of city form must include knowledge on the processes which originated it and those which still determine it. A contemporary definition of urban form must account for the physical patterns as well as the underlying drivers that operate the urban structure, from geomorphology and buildings to people and immaterial networks. Kevin Lynch had anticipated this broader vision when he defined the form of human settlements as *the spatial arrangement of persons doing things, the resulting spatial flows of persons, goods and information, and the physical features which modify space in some way significant to those actions*[5].

The purpose of urban form analysis goes, therefore, beyond the mere description of the physical attributes of cities and its focus varies according to the disciplinary perspective that is taken. The *traditional* approach aims to make sense of urban geometry, which is interpreted as a result of historical processes, events and decisions. The analysis of the fabric unveils the various stages in which the city has been constructed, its spatial patterns acquire meaning and the city becomes legible. The explanatory component of urban analysis helps to understand cities retrospectively and to examine how the relations between processes and spatial form have shaped the contemporary urban structures. This knowledge can then be used to build a theory of design based on traditional processes of city building[6] which, according to this approach[7], ensures the necessary typological coherence of urban transformations. Although this method was used by the Italian school to retrieve historicism in architecture and urban design[8], it is a prospective analysis that does not purport to praise or glorify past interventions but to expose decision makers to the relation between form and performance. It implies the identification of key parameters to explain how cities take a form and how that form functions[9]. If the connection between form and function is consistent, that knowledge can inform urban governance, either to enhance good performance[10] or to mitigate potentially negative effects. In a sense, this has been inherent to planning since its origins, as the repetition of models (from Miletus grid to the garden city) aimed to emulate physical solutions which had proved convenient for different reasons (simplicity, hygiene, troops movement...). However, the contemporary analysis of urban form is an interdisciplinary task, informed by inputs both from the observation of the physical realm and from the

1 As for instance Batty and Longley, 1994
2 Kostof assigns the origin of the word "skyline" to the late 19th Century, but at the same time he dedicates a whole chapter to describe how the representation of skylines have been used over the centuries to portray the image of cities (Kostof,1991)
3 Batty & Longley, 1994 p.42
4 Ibid. Quoting D'Arcy Thompson
5 Lynch, 1981 p. 47
6 Moudon, 1997 p.8
7 This was the aim of the Italian School of Morpholgy
8 Benévolo, 2002 p.598
9 Lynch (1981) coined this approach as "Functional Theory"
10 Or as McHarg put it: form adapts to enhance fitness (McHarg, 1969, p. 173)

analysis of flows in and around cities. Urban morphology can be considered an operative instrument for the planning, design and management of cities which allows the generation of meaningful scenarios to anticipate critical issues.

2.2 Different approaches to urban form

The mid twentieth century was a period of intense activity in the formulation of theories and methods to analyse and provide meaning to the form of cities. Typomorphological studies emerged when the effects of modern planning's doctrines upon existing cities became apparent. Modern planners were accused of examining the existing districts at a very low resolution, and to come up with simplistic diagnoses about the slums, which were to be dismantled and replaced by housing blocks, to provide a better environment. The opposition to the practice of *tabula rasa* in historic districts was initiated in Italy by Saverio Muratori, an academic in Venice and Rome, where he introduced the morphological analysis of the existing city as a mandatory part of design studios[11]. The Italian school of morphology was characterized by two complementary principles: its strong historical emphasis in the typological classification and the continuation of tradition as the basis for city building.

Similarly, the English School, led by Conzen, also addressed the analysis of the existing city as an evolutionary process, introducing the adaptation of the urban fabric to land use changes as one of the main variations respect to the Italian methodology. The analysis of the urban form by the English School starts from the town plan, whose organizational structure is composed by the combination of street patterns, buildings and lots that form homogeneous areas or *plan-units*. The variations of plan-units denote different socioeconomic periods or the adaptation to new land uses.

The third classic school emerged in Paris during the late 1960s. Former students of Lefebvre, among which were Panerai and Castex, formed the Research Laboratory of Architectural and Urban History (LADRHAUS)[12] at the Versailles School. They shared Muratori's concerns about the consequences of modernists' rupture with tradition. Large scale interventions had found a golden opportunity in post-war France due to the need for massive reconstruction. The approach from the Versailles School developed Muratorian theories thanks to the engagement of intellectuals from disciplines other than architecture and geography, such as sociologists, historians and planners. They brought with them instruments typically applied in social sciences and the typological analysis of urban patterns was complemented with statistics and demographic surveys. The French School introduced a new perspective of the urban space: the social dimension and the small scale[13] were emphasized. The city was studied as it was experienced and practiced by the ordinary people. They argued that only by the integration of social activity the physical space is activated and acquires meaning. Savvy readers of the city can infer the social forces embedded in the spatial transformation of the urban fabric.

These three approaches (Italian, French and English schools) shared the idea of urban form as the physical expression of changes in operating forces. Their analytical methods were grounded on the observation of spatial patterns and the focus of their studies was on the historic city. The acceleration of urban expansion and the emergence of new technologies brought about a shift in the scale and an increase in the complexity of urban morphology, giving rise to new theories, objectives and analytical possibilities.

The intense urbanization during the 20th century raised the need for new definitions of the urban domain. The awareness of the large dimensions that cities were taking motivated a shift towards the large scale and the study of cities as a whole, as well as the relations they established with their surrounding regions. Motorized vehicles had transformed the logic of distance as a factor of accessibility, pushing urbanites beyond the city boundaries, boosting new suburban settlements and, essentially, fostering urban sprawl.

The effects of urbanization on the countryside became a major concern. Cities were seen as patches clustered over the landscape. Better living conditions by efficient allocation of land uses and access to nature required the coordinated planning of cities with their surrounding territory. However, overcrowded centres made some degree of decentralization also a legitimate objective, making a case for the new towns that could be designed from scratch as well-performing systems. Proposals for new urban structures adopted a rather coarse approach: neighbourhoods became mere shades, dissolved and undifferentiated, as the attention was given to the relation between urban, suburban and natural areas. Concepts such as edge-city or fringe-city emphasized the importance given to the urban boundary. The border between urban and rural condition defined a new typological classifications of city forms. Initially, categories were based on rather abstract theories, resulting in general analogies such as Spreiregen's sheet-, core-,galaxy-,linear-satellite- cities[14] or Lynch's star-,asterisk-,etc.. In the ninety-eighties, several field observations were conducted over specific regions in Europe[15] and the United States[16] to evaluate how sprawl was actually taking place. These studies revealed the strong influence of the road networks as catalyst of urban sprawl

11 Moudon, 1994

12 Moudon, 1994 p.302

13 Large and small scales are not referred to in their cartographic meaning. Therefore small scale means a detailed approach and large scale a metropolitan or regional scope in this context.

14 Marshall, 2009

15 Font et al 2007, Indovina 2009, Dalda et al 2005

16 Soja 1989

over the European landscape and a progressive densification of the suburban fringe in America. It was a confirmation of a type of urban growth characterized by heterogeneity, spatial fragmentation in a regional scale.

As urban thinkers became more attentive to social processes, the definition of physical components started to lose importance as they could be interpreted as subsidiaries or, as Alexander put it[17], mere *residues* of the activities occurring in the city. The elements of the visual order, which had been key earlier in the century (Camilo Sitte, Modern Movement, Garden City movement, City Beautiful), were not necessarily the ultimate definers of the modern metropolis. Physical form was not essential to determine the level of overall human satisfaction[18] and, in addition, physical planning had entered a crisis and it was being criticised for being too elitist, opaque and anti-social[19].

This shift resulted in a gradual neutralization of the space that was further faded out by the emergence of new information and communication technologies. The traditional role of cities as places of social interaction and commercial exchange (of goods, commodities, services...) was based on spatial concentration to ease access and contact, but new technologies turned the notion of distance and challenged the importance of location. Geographic boundaries were blurred as many of the relational processes concerning a specific city could be happening anywhere else in the globe. However, this new vision of a city whose main characteristics were, apparently, irrespective of the form still needed to be studied and interpreted in some legible terms. Words replaced maps and town-plans in the explanation of the urban reality. Likewise, statistical databases superseded topographic surveys as main analytical instruments. Sociologists such as Manuel Castells[20] or Saskia Sassen[21] built on the flexible notion of location to theorize about the effects in the spatial structures of post-industrial cities, whose form was portrayed by invisible flows (of capital, information...) and whose scale had reached a global dimension. A different theory of flows took an alternative path to comprehend less abstract phenomena, such as the transfers of energy, waste and goods. It gave rise to urban ecology and the earlier metabolic studies in specific cities[22].Despite the apparent contradiction, these formulations were not forewarning a demise of the city. At contrary, they pointed the potential of cities as milieux of innovation[23]. Places where professionals could share and create knowledge to sustain the technological revolution. Only in recent years, mainly due to the increased capacity of computers, it has been possible to analyse the virtual flows induced by urban activities and to visualize the output of these analysis in a meaningful way. Explorations of the urban form can embrace a wider range of issues and yet be decipherable for practitioners from all participant disciplines. One of the main consequences has been the connections that can be made between spatial elements and immaterial flows, integrating the physical and the virtual analysis of the city.

17 Alexander, 1966

18 Lynch, 1981 p.99: "One can be miserable in a island paradise and joyful in a slum"

19 Marshall, 2009

20 Castells, 1989

21 Sassen, 1991

22 Newcombe, 1975

23 Castells, 2000

2.3 Classifications of urban form

According to Moudon, studies of the urban form may be descriptive, prescriptive or critical[24]. For any of these purposes, classification and categorization are typically used to synthesize the heterogeneity of the analyzed scenarios. If the aim is simply to explain how the city was built (descriptive), then the comparison of urban fabrics should reveal consistent attributes for each time period. From this comparison, synthetic models can be distilled to emphasize the fundamental properties of analogous urban configurations. In some cases these models have derived in a sort of canon for city design (precriptive)[25]. In other cases, they have been used as references in the critical analysis of the existing city[26], either to defend it or to denounce the destruction caused by inadequate planning practise.[27]

2.3.1 Typomorphogenesis

The three most prominent Schools of Urban Morphology in the twentieth century (Italian, English and French) shared an understanding of the city in evolutionary terms. Their analysis focused on the rise and evolution of urban types, either at plot, building or tissue scale, but always with the broader context on mind. Parts could not be fully understood in isolation but as constituent parts of a higher hierarchical level. Similarities among the three approaches are partly due to their actual influence with each other but also due to their emergence as response to modern planning operations. Notwithstanding these overlapping ideas, different perspectives and methods were followed in the analysis of urban form.

2.3.1.1 Typologies and Urban Tissue

Although Muratorian theories did not intend to establish a holistic catalogue, his method elaborated on the identification of underlying types in the historical urban fabric. He defined the type as a *priori synthesis of the object's related characteristic*[28], that exists before the object and it is a figurative summary of its essential attributes. This analytical method understood the city as a conglomeration of scalar aggregates, defined by the patterns of assemblage

24 Moudon 1997

25 Specially since the Muratorian theories

26 Specially by the French School

27 Panerai et al 1983 p14

28 Caniggia,G. 1997

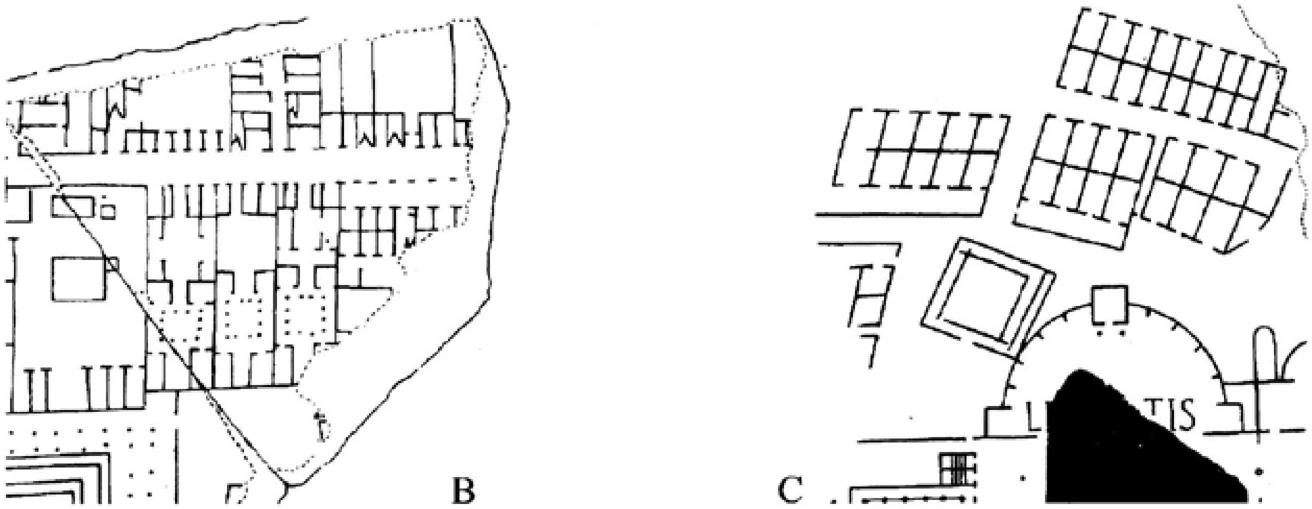


Fig.2-1 Urban tissue composed by patio house types (left) and terraces (right) (Cannigia,1997)

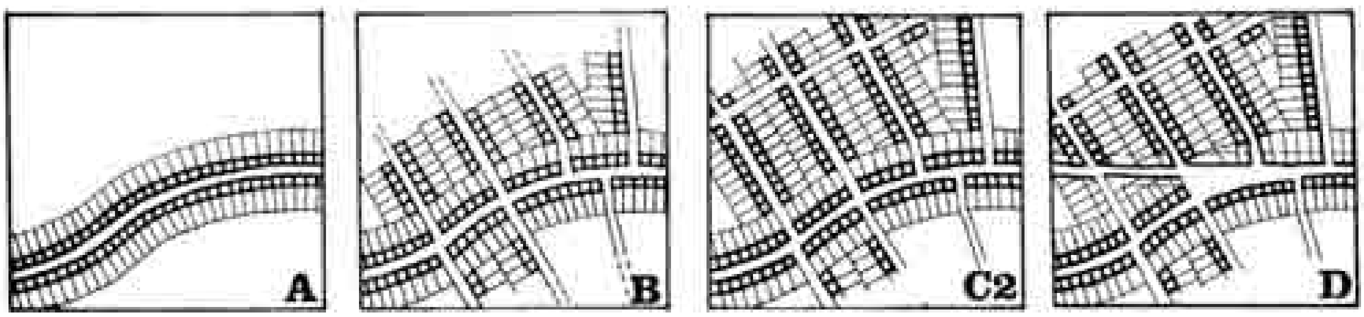


Fig.2-2 Models of urban tissue development. A:parent path, B:establishment path, C:connection path, D:restructuring path (Cannigia and Maffei, 1995)

of lower-level entities. The plot is the basic aggregation unit, whose typological combination determines the character of next level: the urban tissue. The tissue is the equivalent of the typology but at a larger scale and its assemblage makes up the *urban organism* in its totality. Caniggia elaborated different classifications for the plot, the tissue and the urban system respectively, in order to infer the logic behind existing physical configurations[29].

- The **base-type** corresponds to the plot level. It includes the building and associated open space. A first differentiation is made between specialized buildings (churches, markets...) and residential typologies which, due to their preponderance, determine the character of the aggregate. Studies undertaken on Italian cities showed two consistent base-types:

- Terraced house (*insulae*), predominant in Genoa, Florence or Rome
- Patio house (*domus*) which prevails in Milano, Bologna or Naples

- The **urban tissue** (tessuto) is determined by the prevailing building typology and the paths that enable access and connection. Caniggia describes four path categories that originate different types of urban tissues:

- Parent paths. They compose the original urban tissue and they connect poles (or centralities).
- Establishment paths. The new paths that are set in prevision for further edification after the parent tissue has been laid
- Connection paths are those whose layout obeys to the need for access to existing buildings, forming urban blocks.
- Restructuring paths, they have been superimposed over a previous tissue, creating a densification of the fabric.

- The **urban system** is, finally, composed by the

29 Caniggia and Maffei, 1995

combination of urban tissues but also by an area of influence which may include productive land and other settlements which form part of the same system. The hierarchies that are established with the city expansion give rise to models of modular growth, which are summarized in three main categories:

- Barycentric
- Bidirectional
- Linear

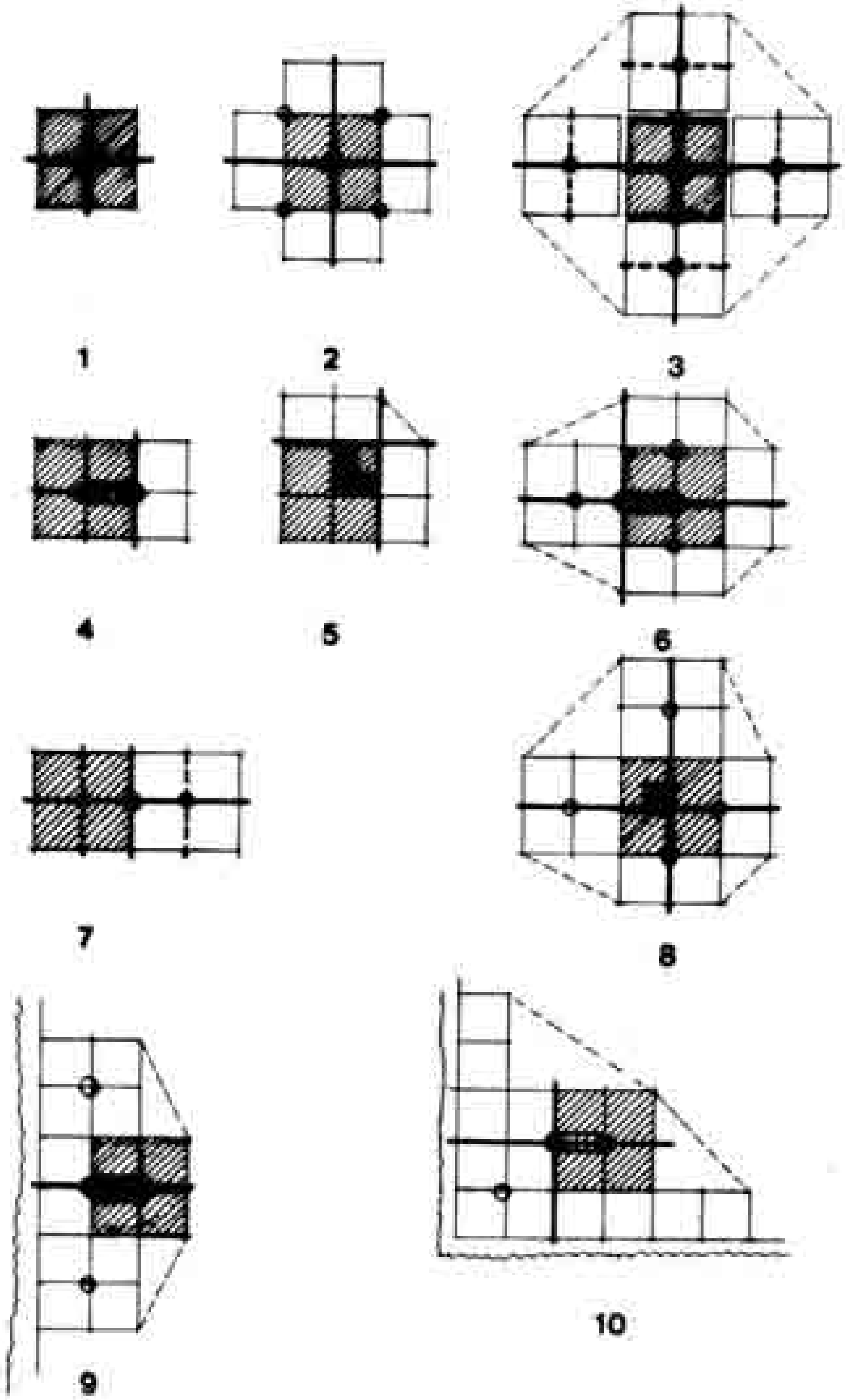


Fig.2-3 Models of modular urban growth. 1: base module, 2:barycentric growth, 3 and 8: Bidirectional, 4,5,6,7: Linear. (Cannigia and Maffei, 1995)

2.3.1.2 Morphological Regions

For the Conzenian School, urban form is read as an stratified compound of three layers (***form complexes*** in Conzenian carefully selected terminology): the town plan, the three-dimensional building fabric and the land and building utilization[30]. These three layers are disintegrated to define homogeneous type areas (each type area is mapped as a hierarchical order) to obtain what Conzen defined as ***morphological regions*** or the town's urban landscape units. Morphological regions are site-specific outputs resulting from surveys and the detailed study of evidences. They are not meant to be extrapolated into models. However, like Muratori and Caniggia, the Conzenian School assumed certain correlations between physical characteristics and the original processes that were instrumental in the shaping of the morphological regions. These correlations were illustrated for Ludlow Old Town in a table that shows how each time period is defined by its spatial attributes (fig 2-4)

Conzen's morphogenetic approach was strongly influenced by his German origins and his training in Geography. One of his mentors, the German geographer Herbert Louis, had studied the uneven manner in which peripheries were being urbanized. Conzen realized the importance of that phenomenon and he evolved the concept of "Fringe Belt" as a distinctive entity whose analysis was necessary to understand, not only the structure of towns and cities, but also the way they should be planned and designed[31]. The Fringe-Belt territory and its associated processes would retrieve the interest of urban analysts, especially in the last quarter of the 20th century, when growth and sprawl were intensified by the progressive densification of these areas. Concepts such as "Edge-city", "Cittá diffusa" or Soja's "Postmetropolis" would address the implications that this change of scale represented for the study of cities.

1	2		3	4
Systematic form complex	Degree of form persistence	Morphological periods	Morphological constituents of historical stratification	Contribution to hierarchy of townscape regions
Town plan	Maximal	High medieval 1090–1270	General outlines of street system, plot pattern and building arrangement	High rank (major genetic plan units) intermediate rank (neighbourhoods: street and precinctual units, high medieval suburbs)
		Late medieval 1270–1500 and early post-medieval	Major island and lateral encroachments on street market, ubiquitous changes to street lines by minor lateral encroachments, ubiquitous minor alterations to plot pattern	Intermediate rank (Eastern Dinham transformation, Bell Lane neighbourhood) lowest rank (morphotopes of market encroachments)
Building fabric	Considerable though varying with periods	High and late medieval 1090–1500	Few but prominent public buildings and defence structures. Very few houses by external indices, but structural remains inside and at rear of many post-medieval houses	
		Early modern 1500–1840	Majority of houses in localized period mixtures	Intermediate rank, but principally lowest rank (morphotopes)
		Victorian and Edwardian 1840–1918	Houses in peripheral location or on minor streets. A few commercial buildings in business core	Lowest rank (morphotopes)
		Inter- and post-war, post-1918	Very few buildings within Old Town	
Urban land utilization		Pre-1840	Major land use areas (business core, residential areas, institutional precincts)	Intermediate rank (traditional business core, traditional residential area, recreational area, castle ruins)
	Minimal	Recent (twentieth century)		

Fig.2-4 Form complexes and spatial characteristics to define morphological regions (Conzen, 2004 p.124)

30 Whiteland, 2007

31 Whiteland 2007

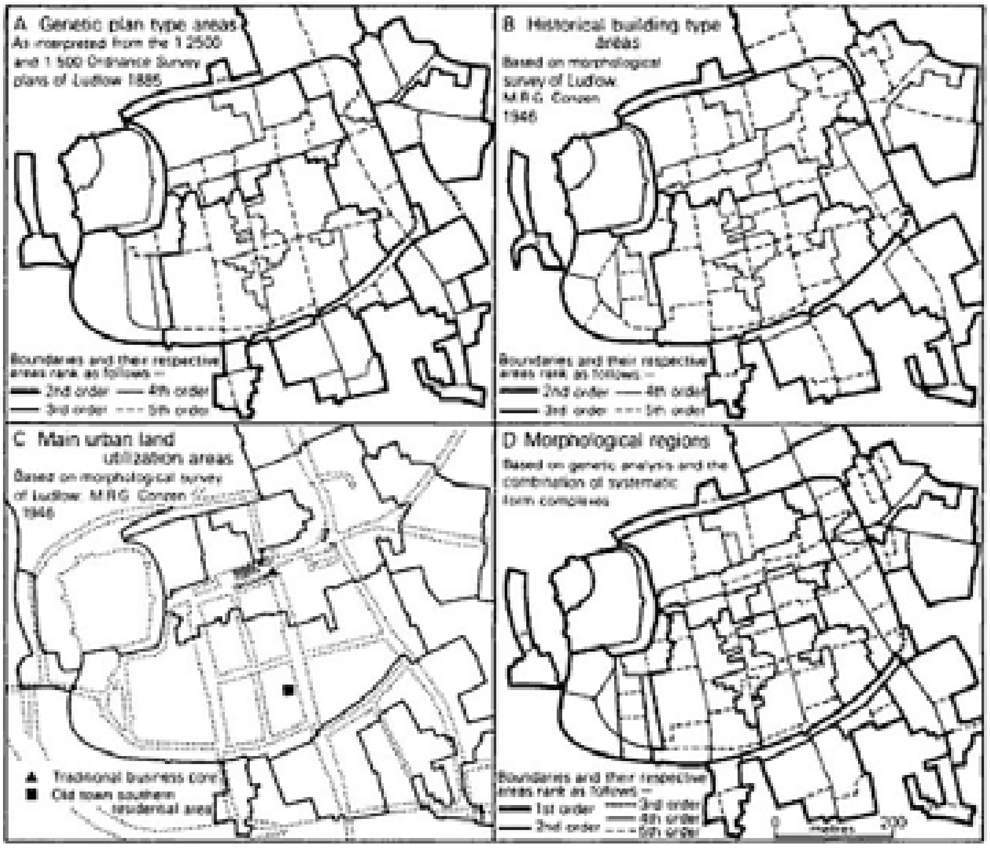


Fig.2-5 Morphological regions as result of form complex analysis in Ludlow Old Town (Shaw, 1998 p.257)

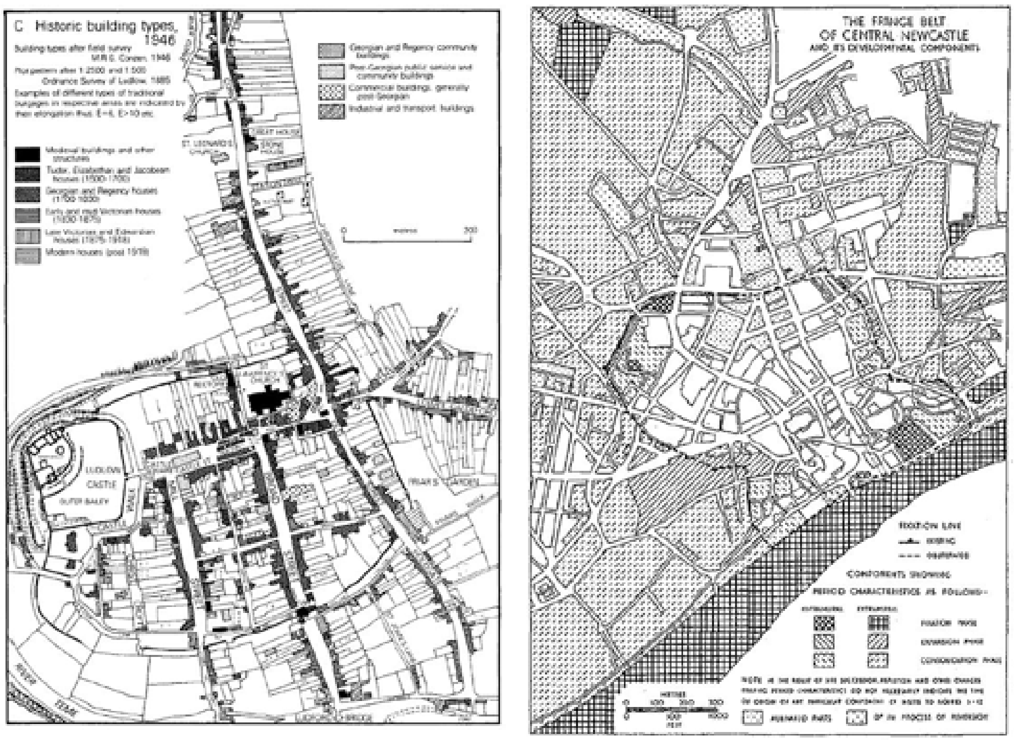


Fig.2-6 Left: Historic building types in Ludlow Old Town (Shaw, 1998 p.257) Right: Fringe belt development in Newcastle. (Whitehand, 1981 p. 55)

2.3.1.3 The in-between realm

The French School of morphology, led from Versailles, combined the Italian approach with Lefevre's concepts of space and formal quality[32]. Their method implies a theoretical rupture between the built structure and the social structure. In this way a first analytical stage acquires a "virtual" objectivity that allows to discover the logic of the systems that organize the built environment. Only then, it would be possible to introduce historical and social aspects in morphological descriptions[33]which are retroactive and current at the same time. The retroactive view of the city classifies the formal aspects of urban growth in two categories:

- **Continuous growth**, which implies maximum density, delimited boundaries imposed by physical barriers and the absorption of hamlets and settlements by periodical extensions of the urban tissue (e.g. Paris). Continuous growth can be further categorized as linear or polar, depending on the distribution of the urbanization process in one or various axes.

- **Discontinuous growth**, it refers to a global description of urbanization over a territory, which includes the old city, the urban extension and intermediate natural patches. The concept relates to Howard and Unwyn theories as well as to satellite cities. It can be observed in long established cities such as London or Bath.

The analysis of city building provides one layer of knowledge, but it needs to be integrated within a broader domain to establish the dialectic between the built and the social environment. Due to the high complexity of the urban phenomenon, the physical analysis has to be reduced to a set of logical and approachable systems. For this reason, the description of the urban structure is based on three basic components:

- **The communication network.** It forms the basic foundational grid of the urban structure. It can be classified as primary network (main roads and avenues) and the secondary network. The redistribution of the secondary network provides the framework to the urban block

- **Public buildings** are exceptions in the urban tissue. Their role is twofold, at the local scale they insert a specific programme and a singular space and, at the city scale, they are a constituent part of the overall structure.

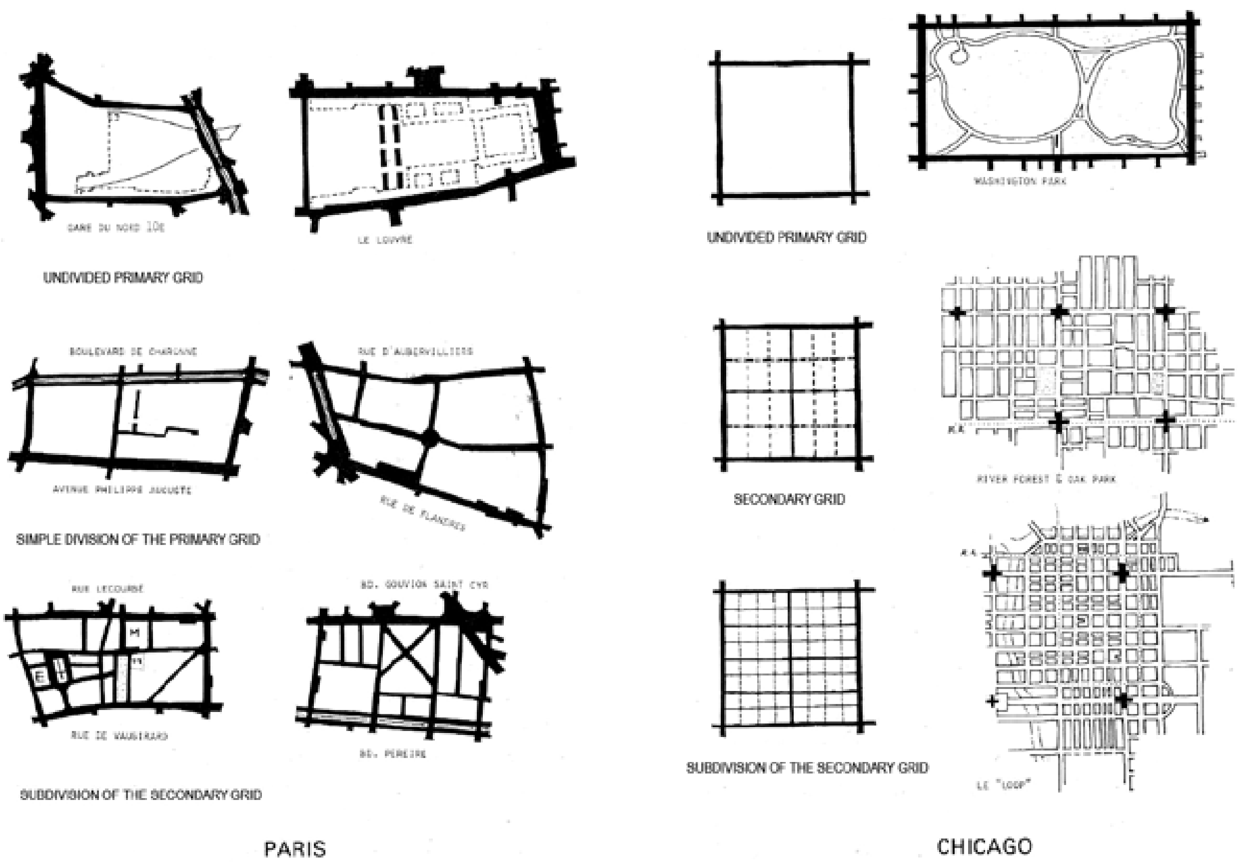


Fig.2-7 Hierarchy of the communication network in Paris and Chicago (Panerai et al 1983, p.222)

32 Panerai et al 2004
33 Panerai et al 1983

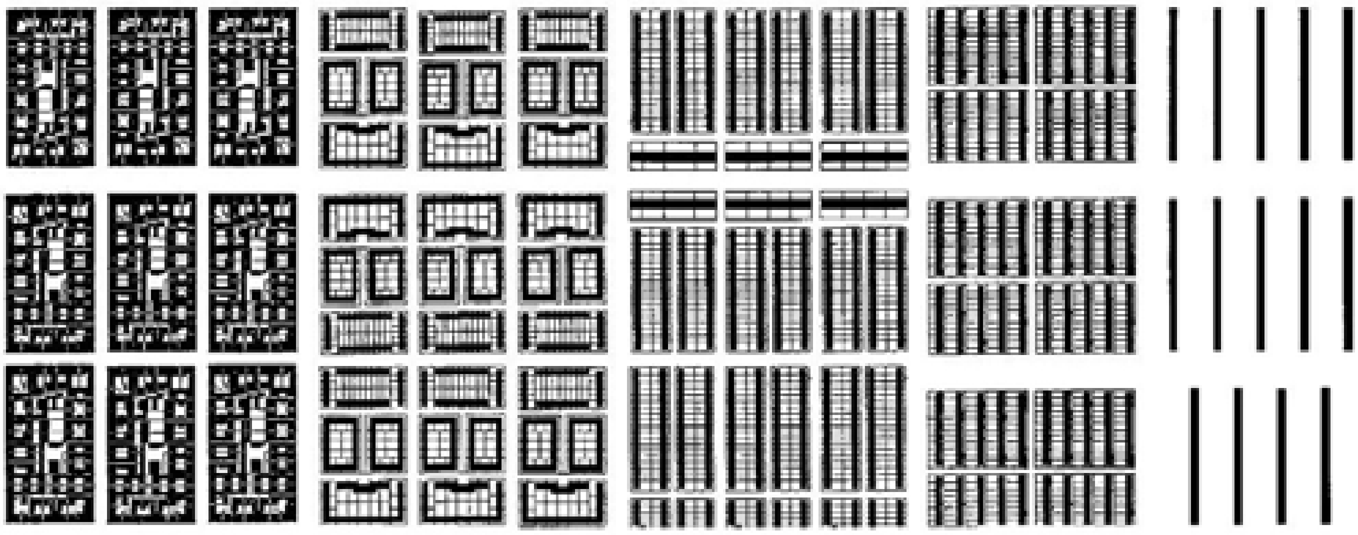


Fig.2-8 Break down of the urban block "Homage to Ernst May" (Panerai et al 2004, p.165)

- **Plot subdivisions and the urban block (ílot).** Although the block is a recognisable entity, it is not necessarily a part of the morphological structure because the city is seldom composed by homogeneous blocks. Panerai understands the block as the scale of local organization of urban tissues, a "long-ignored, in-between realm[34]" that has experienced unprecedented changes since the nineteenth century. The study of these transformations permits to confront the theories that supported them against the built structures and social reality that resulted. Critical analysis conducted in this way concluded that the breaking up of the urban tissue and the demise of the street (modern planning principles) have had consequences in the everyday experience of the city, beyond formalistic and functional logics.

The French School defends a reflective attitude towards the project to overcome the failure of placeless functionalism, advocated by modern planning, as well as the formalistic replication of models regardless of the social context.

2.3.2 The form of the city in the region

2.3.2.1 The natural region

In 1923, the Regional Planning Association of America (RPAA) was constituted by a group of architects, planners, sociologists and ecologists with the aim to promote an alternative way to the congestion of incipient urban agglomerations. They defended that organic planning at regional scale would balance urban growth, preserve natural resources and improve wellbeing. The discourse of the RPAA verbalized a paradigm shift that had been pioneered by Patrick Geddes, Ebenezer Howard and Raymond Unwyn in response to the overcrowding and bad living conditions of English industrial cities. Patrick Geddes is today regarded for his survey-before-planning precept, which, in origin, advocated for the study of the "natural region" as to assess its capacities and to re-organize human activities (including settlements) accordingly. He borrowed concepts and methods from French geographic tradition (de la Blanch, Le Play) and, specially, from geographers with a marked anarchist background (Reclus, Kropotkin)[35], who predicated against the big concentration of industries in cities, deemed as outdatedly wasteful and oppressive, not only for the workers, but also for the general population. As Geddes observed in his "Cities in Evolution", new technologies (hydraulic powered electricity, telephone...) had already made industries less dependent on location but, unlike the wishful auspices of socialist geographers, it was not bringing about a balanced restructure of the social order but an uncontrolled spread of the urban "stain" and its associated problems: the same old story, but at larger scale. This phenomena was coined by Geddes as "Conurbanation"[36], a *conglomeration* of *town aggregates* whose irrational growth caused "the dissipation of resources and energy" and "a depressing life" [37] for the habitants. Geddes' solution, likewise Howard's, lays on the balance between towns and the countryside. He does not reject urban growth but he defends that urban expansion should be planned in accordance with the natural resources of the entire region, to preserve them and to enable population's contact with nature.

34 Panerai et al 2004 p. ix

35 Hall, P. 1988 p.143

36 Geddes 1915, p.34

37 Ibid. p. 86

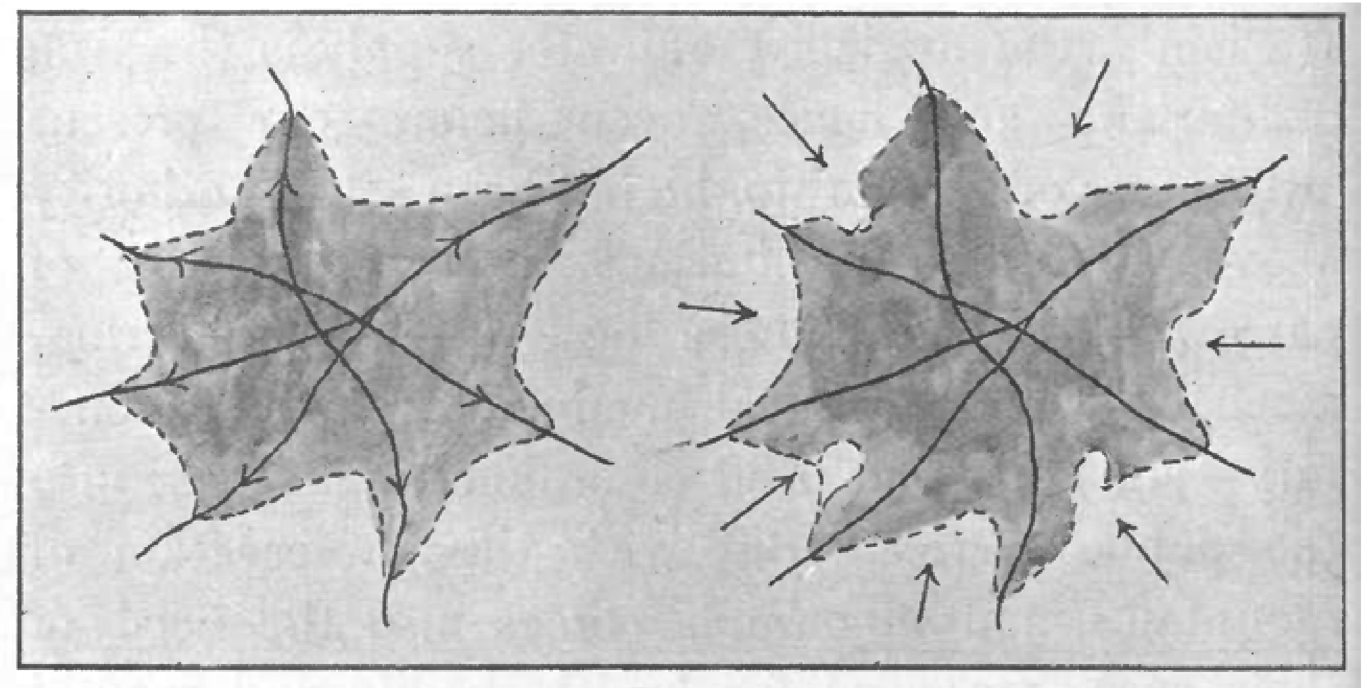


Fig.2-9 The naturalization of the city as opposed to urbanization of the countryside (Geddes 1915)

Lewis Mumford, as the main voice of the RPAA, assumed most of Geddes' theories. He articulated the benefits that a regional approach could have for urban welfare in his renowned "Culture of Cities[38]". In this collection of writings, which he started "under the stimulus of Patrick Geddes"[39], he rhetorically challenges the reader to fly over cities such as London, Berlin or New York and to attempt to discern their shapes. This would be a hopeless exercise as he warns about the shapeless expansion of great cities. That "Amoebic" growth has swallowed up old villages (Harlem, Manhattan in New York, Chelsea or Kensington in London), increased urban distances, worsened overcrowding and had no other logic than financial speculation. To combat this combination of urban congestion and sprawl, the implementation of regional planning, he argues, could provide "scientific knowledge and stable standards of judgment, justified by rational human values, to the exploitation of the earth"[40]. Essentially, the RPAA advocates for active planning, which is not limited to land use control or partial prohibitions but it is provided with positive powers on what shall be done to preserve the natural resources in geographically delimited regions. This line of thought, which connects Ebenezer Howard and Patrick Geddes with Abercrombie's Greater London Plan (1944)and Ian McHarg's environmentalism (1969), is not as concerned about the specifics of the urban tissue as for the overall organization of the urban continuum. The city is observed from above, using schematic maps which are explanatory illustrations rather than analytical instruments (except in McHarg's methodology, although even there, the attention is put on the natural region while the city remains diffuse). Despite the limited influence of the RPAA during its lifetime, the explosion of the city became a major topic in the ninety sixties and numerous studies attempted to characterize the forms that cities were taking as a result of their continuous expansion.

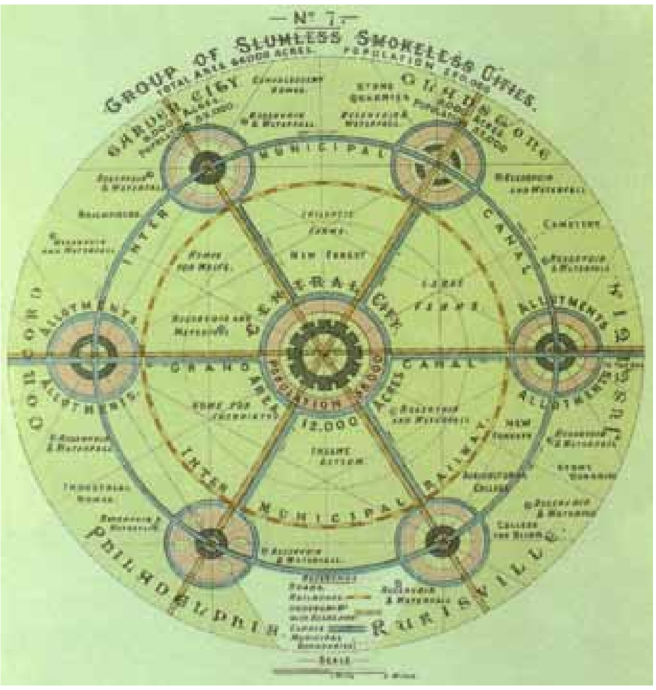
2.3.2.2 A taxonomy of metropolitan form

The analysis of the metropolitan form has been approached in diverse ways: retrospectively or prospectively, descriptively or prescriptively, comprehensively or type-specific... Unlike typological studies, there has not been a predominant school. The record of articles and publications reveals a period of maximum interest from the ninety fifties until the mid sixties. Urban models were listed and assessed in comprehensive catalogues. The interest on the topic diminished during the seventies and eighties, to re-emerge in the nineties, mainly in form of ad-hoc studies to reflect a prevailing idea (e.g. cittá diffusa) or to reassess earlier theories under new criteria and analytical tools (e.g. Marshall, Font...).The lack of a established school did not prevent the exchange of ideas among urban experts or the establishment of an coherent body

38 Mumford 1938

39 According to Hall (Hall 1988 p 139) Geddes wanted to turn Mumford into his assistant in 1923, after his refusal they barely communicated again. However, Mumford recalls a previous meeting in 1915 as decisive in his preface for the first edition of Culture of Cities (Mumford 1938)

40 Mumford 1938 p329



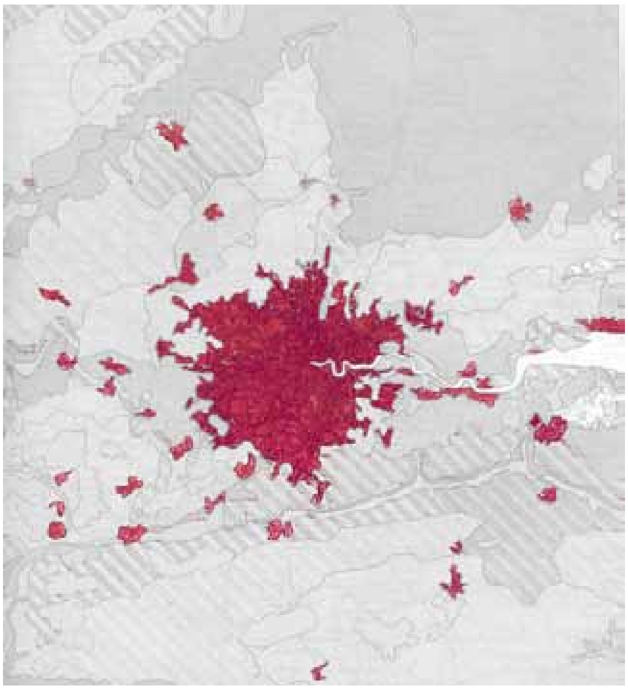


Fig.2-10 The city in the region as depicted by Howard (Howard 1902) and Abercrombie (after Abercrombie 1944)

of published literature about metropolitan patterns. Among these, four interconnected authors and reputed practitioners left a significant influence that reached contemporary studies of city form: Kevin Lynch, Paul Spreiregen, Hans Blumenfeld and Konstantinos Doxiadis were among the most prominent authors in the ninety fifties and sixties. The two former shared training at MIT, Spreiregen collected and edited the essays of Hans Blumenfeld[41] who kept a public discussion about Copenhagen plan with Doxiadis[42], which was known and quoted by Lynch[43], thus closing the loop.

Kevin Lynch was explicitly ascribing urban quality to city form when he suggested a number of alternatives to be evaluated against their capacity "to realize the potential of metropolitan life"[44]. In his approach he identified the three basic elements that configure the spatial pattern of cities: structural density, circulation system and the location of city-wide activities that serve large areas (governmental buildings, factories, shopping centres...). The character of these elements define three decisive features: the urban grain, the focal organization and accessibility, which would be further developed into more complex performance attributes, such as sense, vitality, adaptability or comfort to be used as criteria for evaluation. Following this structure, five models were presented and assessed, under the assumption that they could exist as pure types[45]:

- Dispersed Sheet
- Galaxy of Settlements
- Core City
- Urban Star
- Ring

Due to the inability of any of those types to meet some of the basic objectives, Lynch proposed the use of composite models, which would respond closer to the complexity of real cities. The study of identifiable performance characteristics, which were derived from spatial qualities, could be generalized as long as they can be measured and scaled. Only then, models of settlement form (regarding its general patterns, textures or structure) could be prescribed to meet a performance dimension objective[46].

Blumenfeld and Spreiregen formulated their morphological classification in the context of a descriptive chronicle of planning and city form theory. The former understood the modern city as a product of historical evolution, whose turning point was brought about by improvements in transportation and the subsequent separation of work and residence location or, more broadly, the separation between place of production (including dwellings as labour production nodes) and the place of marketing (including the office or

41 Spreiregen 1967 preface
42 Ibid. p 93
43 Lynch 1961
44 Ibid.

45 Ibid.
46 Lynch 1981 p.112

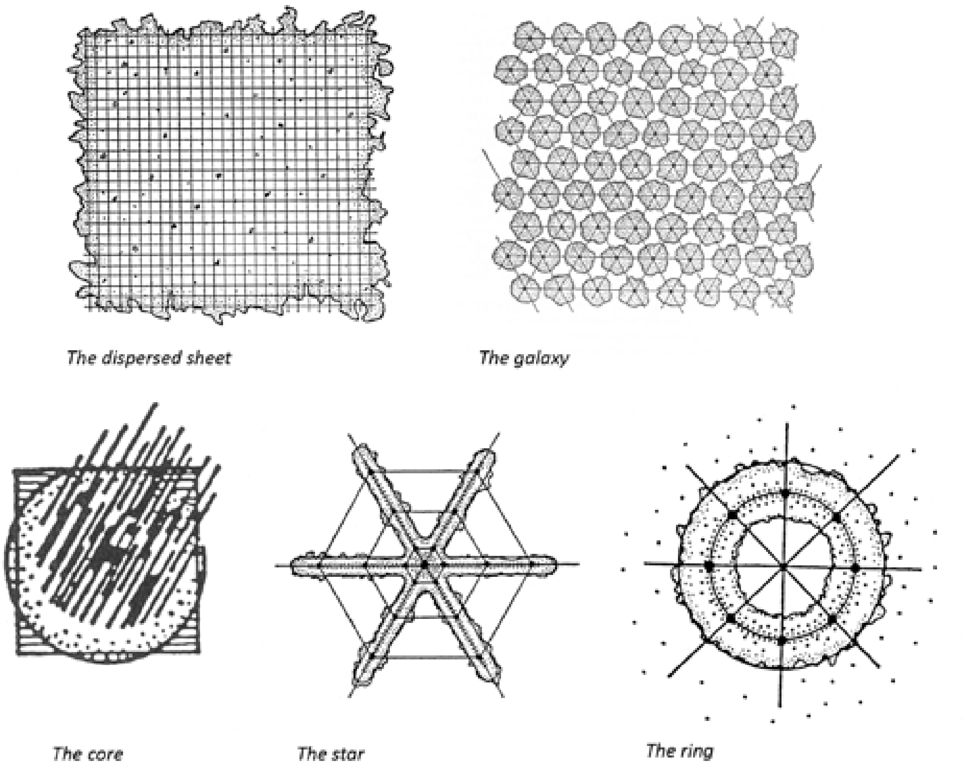


Fig.2-11 Kevin Lynch´s patterns of metropolitan form (Lynch 1961)

factory where the worker markets his skills)[47]. Nevertheless, the basic patterns he describes to characterize contemporary models are based on rather loose observations[48]:

- Concentric City
- Linear Ribbon City
- Satellite City
- Star-Shaped City

Blumenfeld reads Le Corbusier's Radiant city as a modern version of traditional concentric growth and foresees a star-shaped city as the rational response to the ever-changing needs of the city of the future . Spreiregen went a bit further as he related models with actual cities, which brings a layer of reality to the previous abstraction. He put forward eight categories (fig.2-12) that he had distinguished after analysing the internal structure of cities such as Los Angeles, Dallas,Stockholm, Stalingrado or Detroit. Some of these models match Lynch's categories and both will be retrieved in recent research[49]:

- Sheet
- Core
- Galaxy
- Satellite
- Star
- Linear
- Ring
- Polycentered Net

The fourth reference that would complete this taxonomy was formulated by Constantinos Doxiadis, a Greek architect and urbanist who developed a theory on human settlements that he coined after the Greek term "Ekistics"[50]. He argued that the study of cities should be elevated to the category of science, a science that should encompass knowledge of urban evolution and principles to inform city planning in terms of size and quality[51]. He derived those principles from the observation of city-making over history. From this analysis, five elements were found as common objectives to attain urban quality:

1. Maximization of contact with nature
2. Minimization of the effort required for interaction
3. Optimization of shelter, this includes protection against enemies, animals and climate
4. Optimization of environmental quality, it has to do with order, art, aesthetics...

47 Spreiregen 1967 p.33
48 Ibid. p.35
49 Spreiregen 1965
50 Dioxadis 1970
51 Ibid. p.393

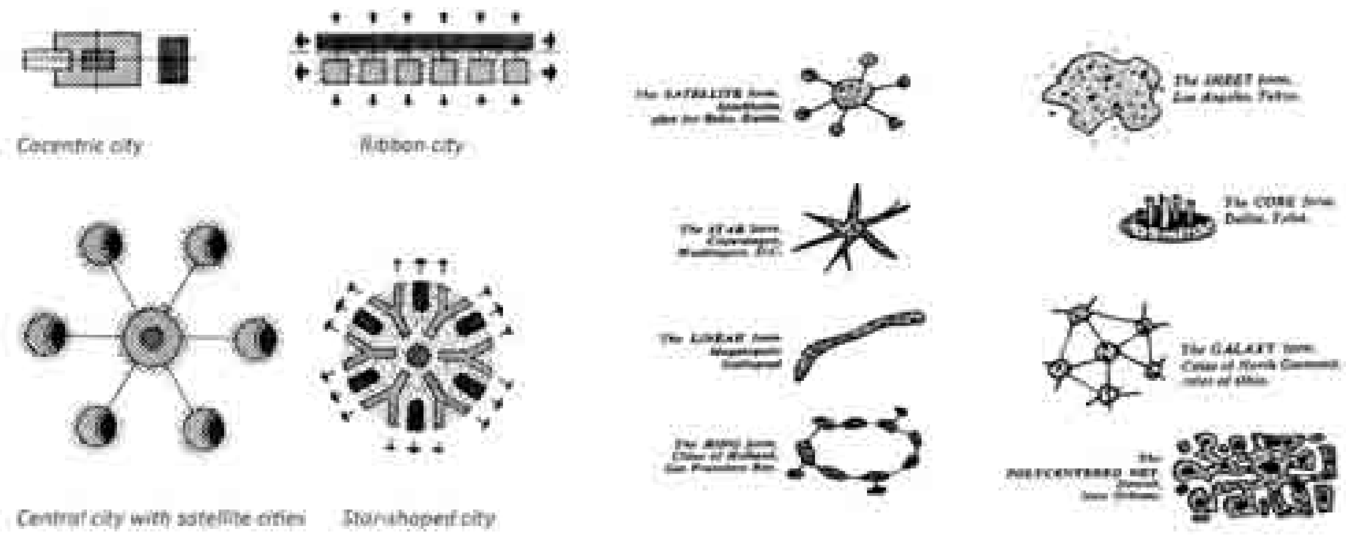


Fig.2-12 Schemes of city patterns by Blumenfeld, left (Spreiregen 1967) and Spreiregen, right (Spreiregen 1965)

5. The fifth principle would be the optimal synthesis of the four previous principles. If these principles were achieved in a balanced way, the settlement would be successful.

Doxiadis' depiction of urban morphology (fig. 2-13) is both retrospective and prospective. The combination of the basic principles have resulted in traditional settlements having a limited size, one that would allow city-wide pedestrian access, and a circular shape, to maximize access to the central point with a minimum perimeter (in the event that walls were needed). This original "polis" remained in steady balance with the region that supported it, until the Industrial Revolution of the nineteenth century, when railroad transport allowed faster and further inland communications, thus inducing what Doxiadis coined as "Dynapolis", a city of increased mobility. Urban evolution continues with two morphogenetic stages that he termed "metropolis" and "megalopolis". They were the result of the acceleration of urban expansion due to the advent of the automobile and the dissolution of former political boundaries respectively[52]. Finally, he foresaw the city of the future: the Ecumenopolis, a worldwide city composed by networked settlements and communication paths that would incorporate parts of countryside within its fabric. Doxiadis advocated for the assumption of this inevitable fate and to plan accordingly in order to ensure high quality in future urban developments.

52 Dioxadis 1962 p.215

The search for a conceptual definition of the modern metropolis centralized the urban debate that followed[53]. Doxiadis defended the scientific validity of the research methods that led him to postulate his city of the future. From the observation of urban form evolution he inferred a future trend and a conceptual model. Likewise, various authors engaged this kind of generalizations to describe the urban phenomena. Many of them paid special attention to the acceleration of the urbanization process in their definitions. Jean Gottmann's "Megalopolis"[54] drew one of the most influential studies about urban decentralization in the sixties, as suggested by the use of this term by Doxiadis, Blumenfeld or Lynch. The Megalopolis conveyed metropolitan areas that contained more than one city as result of the process of decentralization from big central cities to smaller adjacent ones[55]. To a greater or lower extent, a majority of European regions could be soon ascribed to that definition. However, the form of urbanization in the landscape was approached more intensely during the ninety eighties. Specific studies were conducted for the regions of Veneto, Flanders, Catalonia or Galicia (fig.2-14) to reveal the nature of sprawl over those territories. Although Gottman's ideas could be identified in these texts, the term evolved to a more general "diffuse city", in relation to a seminal text by Francesco Indovina.[56]

53 Spreiregen 1967 p.61
54 Gottmann 1961
55 Hall and Payne 2006 p.3
56 Indovina 1990

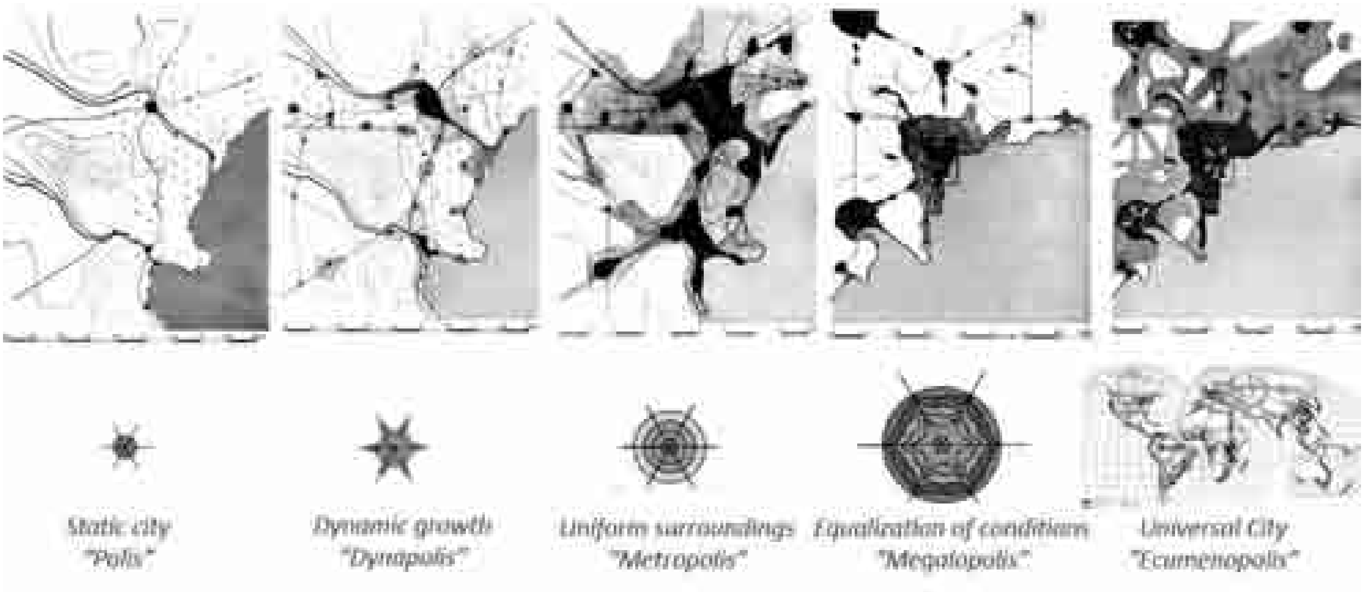


Fig.2-13 The evolutionary stages of the city in the process towards Ecumenopolis (after Doxiadis 1970)

The densification of suburbia and the progressive dissolution of the urban - rural duality caused traditional morphological studies to be virtually superseded by monothematic dissertations about the logics and parameters that characterize urban sprawl and polycentricsm[57]. European cities were evolving towards decentralized megalopolitan patterns that had occurred in America several decades earlier. A current of thought that tended to understand cities as uniform entities was not but a result of the actual homogenization and loss of singularity in urbanized regions at both sides of the Atlantic. The assessment of alternative city forms had found a last blow in Kevin Lynch's "Good City Form", a comprehensive essay that recollected ideas from the previous thirty years and anticipated important questions such as the use of key performance indicators[58] to evaluate the fitness of each form. After this publication, mainstream research was trying to capitalize new analytical tools, specially (but not only) emerging Geographic Information Systems (GIS), which facilitated complex data handling in urban and territorial analysis. The combination of GIS and extensive and accurate cartography encouraged research teams to explore, in a quantitative way, some of the concepts that had been raised in previous years. The metropolitan form could thereafter be systematically quantified, causing great excitement to the advocates of a more scientific and multidisciplinary approach to urban analysis. Morphology became a subordinated subject under the heading of urban development. Instead of holistic city models, the debate was monopolized by quantifiable variables, such as compactness or density. This can be interpreted as an influence of the reduction of built forms to mathematical relations that had been explored by systemic planning and the studies by March, Steadman or Martin in Cambridge.[59] Nevertheless, the taxonomic designations remain useful in comparative analysis of spatial policies as they provide meaningful descriptors to relate with transport or energy performance[60]. The use of urban models in relation to performance will be thoroughly discussed in following chapters.

In recent years, original metropolitan typologies have been seldom proclaimed. Most studies have retrieved concepts that were already formulated in Spreiregen or Lynch's publications. In some cases, types are almost literally borrowed from a compilation of different sources. Hildebrand Frey[61] described six alternative city models he collected from Lynch (Core, Star and Galaxy),Blumenfeld (Linear, Satellite) with the addition of the Polycentered Net, proposed by Spreiregen. He also commented on variations of those models, such as the Transit Oriented Developments (TOD) that were formulated by the New Urbanism movement[62] and uses this taxonomy to theorize about the eventual impact upon the environment of each form. Stephen Marshall[63] is, in principle, not as concerned with overall geometries but with the internal urban structure (topology). His initial classification of urban form aimed to reflect the

57 See Hall and Payne 2006 or Jacobs 2000

58 Lynch 1981 p 112. He suggests that the establishment of performance indicators would be advisable to assess the fitness of urban form. In 2009, BREEAM and LEED launched their indicator-based assessment methods for the urban scale.

59 See for instance Steadman 1983

60 See for instance Owens 1987 or Newton 2000

61 Frey 1999

62 Calthorpe 1993

63 Marshall 2009a

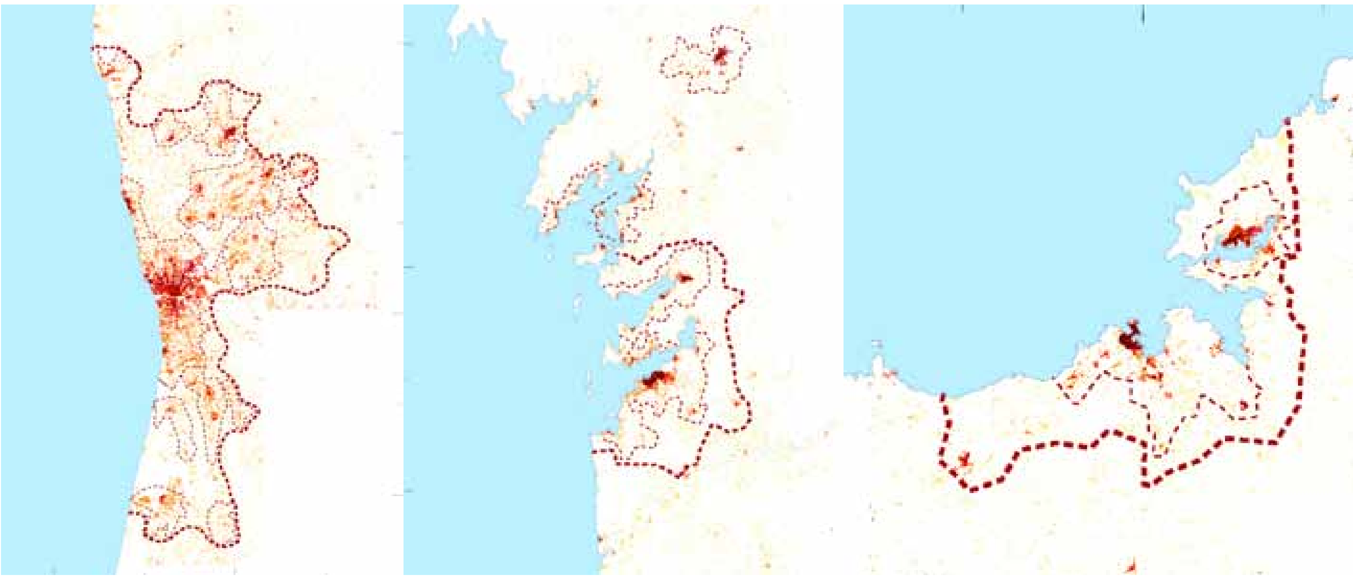


Fig.2-14 Difusse City in the Altantic Axis Galicia-North Portugal (Dalda et al 2005)

basic differentiation that is present in almost every city. Essentially, he recognized two fundamental components: the centre and the suburbs. In a second level, further sub-centres may also appear. Based on this basic assumption he simplified Spreiregens' eight typologies and came up with six urban models:

- Monolithic
- Core city with Satellites,
- Constellation
- Monocentric,
- Hub and Sub
- Polycentric

And three variations:

- Monolithic linear
- Monocentric Linear
- Constellation Linear

In a later study, Marshall went one step further and he connected conventional typologies with mathematical attributes. He indentified three basic characteristics to define urban form:

- Compactness
- Linearity (or spinality)
- Polycentricity

The quantification allows the creation of typologies that could be specified as future forms.[64] He finally illustrated this classification in a matrix where city (local option) and regional form (strategic option) were combined (fig.2-15).

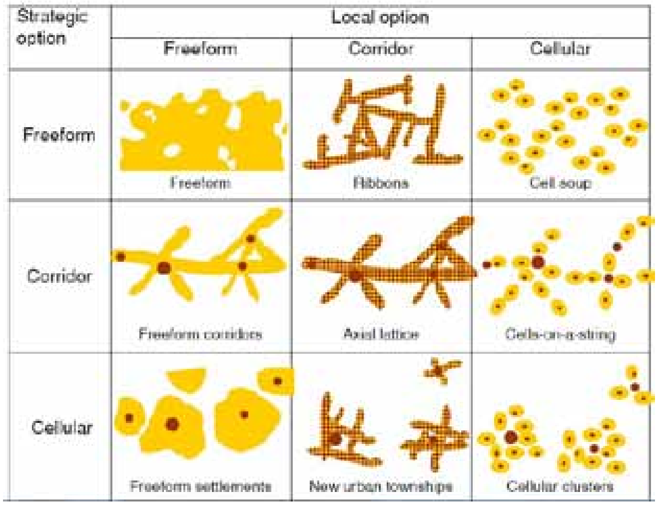


Fig.2-15 Composite forms combining city centres, sub-centres and suburban area (Marshall 2009b)

64 Marshall 2009 b. This study is part of the broader research project SOLUTIONS, that "focuses on spatial policy, in terms of design, transport systems and built form, in outer city areas of the UK that are experiencing or are likely to experience growth pressures in the future"

Table.2-1 Most common typologies used to characterize metropolitan form

Core, Monolithic, Compact	Lynch 1961, Spreiregen 1965, Frei 1999, Forman 2008, Marshall 2009,
Star, Monocentric radial	Lynch 1961, Spreiregen 1965, Blumenfeld 1967, Frei 1999, Forman 2008, Marshall 2009,
Dispersed sheet, diffuse city	Lynch 1961, Spreiregen 1965,Indovina 1990,Font 2007, Forman 2008
Galaxy, Contellation	Lynch 1961, Spreiregen 1965, Frei 1999, Marshall 2009,
Satellite	Spreiregen 1965, Lynch 1981, Frei 1999, Marshall 2009, Forman 2008
Megalopolis, Polycentered Net	Gottman 1961, Doxiadis 1962 Spreiregen 1965, Frei 1999, Jacobs 2000, Hall and Payne 2006, Font 2007, 2009

2.3.3 The invisible city form

As it can be inferred from previous paragraphs, city making was rarely understood as a neutral process of pure physical assemblage. Urban layout and built fabric are a result of interacting forces of different nature[65] that produce a particular shape at a particular moment in time. The relational city theory refers to the portrayal of urban form beyond its physical shape, with an emphasis on invisible aspects and virtual processes that may be reflected in the spatial structure of the city. It has been an expanding field since the ninety fifties and, after some vacillating periods, it has achieved a great projection in the early twenty first century. As Kostof described it, “a grid is a grid is a grid” only for the form-seeker[66] but urban patterns are actually impressed with specific cultural intentions whose understanding becomes critical. Batty quotes D’Arcy Thompson[67] to justify the examination of processes in spatial analysis, given that form is essentially a “diagram of forces”. There is an immaterial component of form which is present in almost every definition of city[68]. The only difference resides in the disciplinary perspective. Cities can be read as “problems in organized complexity”[69] which are interpreted differently through the lens of the sociologist, the historian, the transport engineer or the architect.

In the mid fifties, geographers realized the potential of economic forces to determine land uses when they rediscovered the old work on location theory by German geographers Von Thünen (1826) [70] or Christaller (1933)[71]. It was the starting point of an intellectual revolution in social sciences and particularly in planning: “the systems revolution”[72]. Cities were seen as systems whose evolution was determined by complex operating factors that could be measured, manipulated and optimized[73]. Scientific analysis based on regularities found in spatial processes could be used to correlate acting forces and to predict the evolution of the system. The first attempts to model urban activities started with transport and road networks. In those early models, linear and traffic patterns were derived from land use distribution and road capacity that were given. The dynamic systems theory[74] proposed, in contrast, iterative models without definite goals for a better identification of critical factors. The increased complexity of the models was only feasible with the use of computers that, although primitive from today’s perspective, allowed greater data handling. The so-called systems approach confronted current planning practice at the time, which was seen as too deterministic[75], imposing preconceived blueprints that would be difficult to adapt to ever-changing needs. Urban modelling acquired a great relevancy, as its quasi-scientific status provided planners with irrefutable arguments to defend their postulates, as opposed to wishful thinking and inspiration that seemed to inform traditional planning decisions. Universities such as Manchester, Reading or Cambridge enthusiastically engaged the teaching and elaboration of mathematical urban models as part of their planning curricula and research agenda.[76] However, the momentum would decline in the seventies due to a loss of confidence on a method that had never been fully accepted by sceptic planners. This reluctance was justified by the metaphysical claims and limited transparency of the models which, after all, were only as good as the data and assumptions taken by some alleged experts. Two aspects fuelled the decline of systems theory: first, a new paradigm shift in planning, towards a bottom-up approach which demanded wider public involvement and, secondly, the concerns about the validity of models that were publicly expressed by renowned voices such as Solá-Morales[77]

65 Alexander 1966, Hall 1988, Batty 1994, Marshall 2009
66 Kostof 1991 p.10
67 Batty 1994 p.42
68 Jacobs 1961 , Alexander 1966, Lynch 1981,Kostof 1991, Batty 1994
69 Jacobs 1961

70 Von Thünen showed how concentric rings of land could form due to the different prices of agricultural products located at different distances from a central market. Visit to download A computer simulation model based on Von Thünen’s theory created by Phillip Steadman at UCL can be downloaded from UCL- CASA website (UCL-CASA,2013)
71 Christaller elaborated a theory of central place, he argues that the distribution of uses obeys to an orderly distribution generated by trading decisions. “In the case of an homogeneous plan, towns would be expected to arrange themselves in an almost hexagonal hierarchical formation” (Marshall 2009 p.185)
72 Hall 1988 p.327
73 Batty and Marshall 2009, March 1967 (in Martin and March 1972)
74 Forrester, 1961
75 Hall 1988
76 See for instance Echenique 1968, Batty 1976
77 Solá-Morales Rubio, 1972

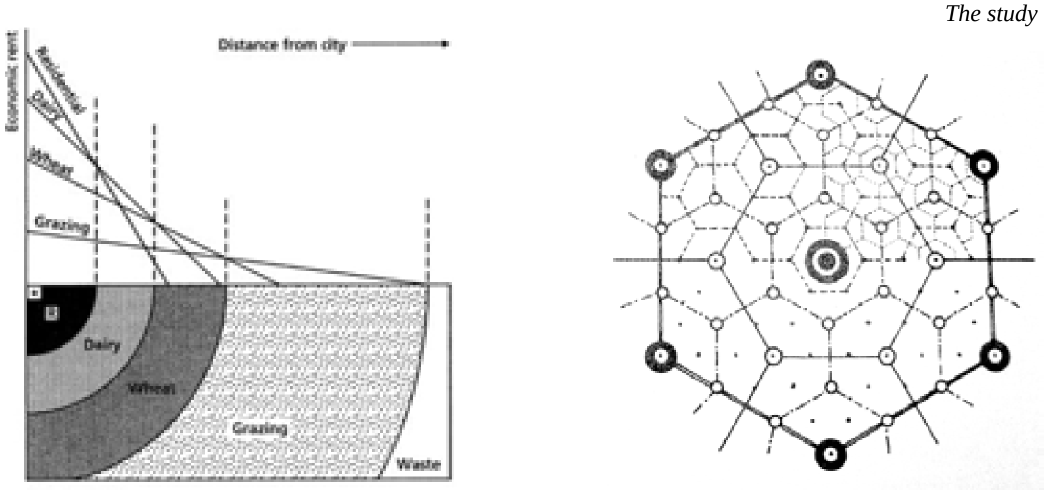


Fig.2-16 Left: Von Thünen model of concentric rings (Mayhew, 2010). Right: Christaller diagram of centric place theory (Christaller, 1966)

or Briton Harris[78]. Systems principles were subdued to subsidiary studies that could be eventually consulted to inform certain planning decisions.

However, the underlying idea remained: processes could explain form and, conversely, the physical structure of the city would determine what processes would occur and how. This was, essentially, the hypothesis that justified systemic studies and inspired a body of literature that, although not directly bounded to systems theories, shared its emphasis on processes. It comprised a series of studies that explored the connections between changes in social, institutional and economic structures with trends observed in urban transformations. The impact of communication and information technologies was seen as a critical factor, to the extent that they could result in the eventual demise of cities[79]. This argument was not generalized for the most influential studies found cities as the necessary places where "globalization tasks take place"[80] and were sceptical about people working in "technological cottages" spread over undefined territories[81].

Although theory on networked cities is diverse, three intertwined topics can be recognized:

- Globalization
- Communications
- Virtuality

These three issues are closely knitted as they build on the refashioning of social and economic relations induced by fast-changing technologies. Nonetheless, they have different connotations depending on the scale of the observations. For each category there is a major bibliographic reference: while Sassen[82] and Castells[83] elaborated the most influential theories about global and informational cities respectively, virtual cities were portrayed in Will Mitchell's "City of Bits" as disembodied places that coexist with actual cities. They are yet to be moulded in a process that, he argued, will compel important challenges for designers. Castells explained how the urban social restructuring created new spatial logics in cities and regions. The notion of location has been altered but not completely stripped of its spatial component. The new flows of information and communication allowed the relocation of certain business sectors (especially those related with IT), exemplified in Los Angeles' suburban densification (depicted by Soja[84]). As long as firms were strategically positioned in the invisible informational network the need for centrality and physical proximity became secondary. However, he added, business leaders and decision makers are not indifferent to the environment that surrounds them and, in a context where interdependency is commonplace, the dissolution of central business districts seems unlikely. That connects with Sassen's Global City concept, which sharpened insights on how world-wide flows of capital have concentrated power and wealth in certain locations that possessed the favourable conditions for financial activities to flourish. Although these conditions have had political and economical roots they have also affected urban patterns due to their need for, on the one hand, visual landmarks to highlight in the global hierarchy and, on the other one, dynamic cosmopolitan environments to attract skilled executives. The second aspect has also intensified class dualities, as jobs that were created did not match with those which had been destroyed. Class conflict arose as blue collar labour was replaced by white-collar workers and, on its spatial version, shiny office buildings took over former manufacturing states.

78 Hall 1988 p.331
79 Webber, 1964
80 Sassen 1991
81 Castells 1989

82 Sassen 1991
83 Castells 1989
84 Soja, 2000

Fig.2-17 Class duality and conflict in the post-industrial city: Council blocks for low income tenants and abandoned industrial sites coexists with the places of globalization

This kind of connections between economic and social readjustments and urban patterns are deeply embedded in the analysis of the post-industrial metropolis. From the sociological perspective, the form is a structure of relations, which are better described by words than by images. These studies have articulated the challenges that cities were facing at the turn of the century: social polarization, urban marketing or gentrification were rightly anticipated by them. They got across their message and set the theoretical background for generations of scholars who were now equipped with sophisticated visualization tools and a broader research capacity. Institutions aiming to be at the cutting-edge of urban studies, embarked ambitious programmes to investigate how cities, peoples and activities performed. They borrowed analytical instruments from the old systemic approach to merge it with avant-garde social science. A greater emphasis was placed on the observation and monitoring of actual behaviours and less on the feedback loops established by iterative simulations (even though computers were key analytical tools). One of these earliest efforts was reported in "The Social Logic of Space"[85], a book in which Hillier and Hanson advanced a new methodology to describe "how environments acquire their form and order as a result of social process"[86]. The theory was accompanied by a set of analytical tools for researches and designers, with a distinctive graphic representation of urban networks: space syntax. A decade later, Batty[87] and Longley published "Fractal Cities"[88], where they combined principles of systems with new visualizations of urban dynamics to unveil an underlying order out of apparently chaotic urban growth. The book, as heavily apparelled with mathematic formulations as the archetypical texts from the seventies' systems theory, anticipated the broader research that Batty would lead as founder of the UCL's Centre of Advanced Spatial Analysis [89](CASA), a multidisciplinary research centre with a strong focus on complex models and the visualization of urban flows and processes. The research conducted at CASA exemplifies the shift from individual postulates (Lynch, Doxiadis) to multidisciplinary team that follow complementary lines of research. There are, at least, two other internationally reputed institutions with undergoing research programmes about contemporary cities that could fit this descrition: the Massachusetts Institute of Technology Senseable Lab[90] and the London School School of Economics Cities Programme[91]. The former has taken a highly technological approach. The city is monitored by means of multiple sensors, which are actually carried by the inhabitants as a result of the generalization of personal communication technologies (cell phones, internet flows, GIS...). The interpretation of "crowd-sensing"[92] provides insights about behavioural transformations in the city, which are then developed into experimental "urban-demos which engage people in experiencing possible future scenarios"[93]. The urban form is the form of flows and sequential snapshots, concentrations and different intensity levels of human activities. Their proposals aim to organize and facilitate those activities by means of software instead of traditional physical interventions (hardware). On the other hand, the LSE Cities programme focuses on how "the design of cities impacts on society, culture and the environment"[94] to shape a new thinking on how to improve them. Despite this general declaration they have fed the knowledge of cities with numerous publications and reports from multidisciplinary research where social analysis became visible and overlaid to physical urban structures.

85 Hillier and Hanson 1984
86 Ibid. p.8
87 Batty had been engaged in systemic planning in the Universities of Manchester and Reading
88 Batty and Longley 1994
89 See www.bartlett.ucl.ac.uk/casa
90 MIT City Senseable Laboratory (senseable.mit.edu)
91 LSE Cities (lsecities.net)
92 Nabian & Robinson,2011
93 Biderman et al, 2011
94 The initial statement at lsecities.net

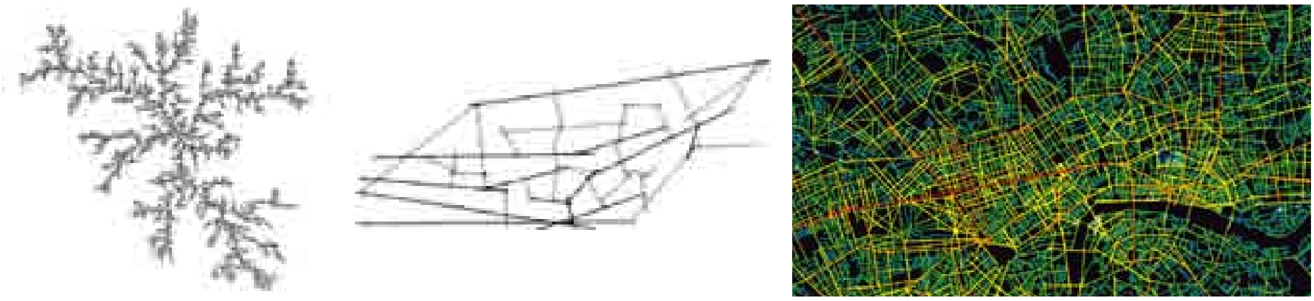


Fig.2-18 Left: Fractal growth (Batty and Longely 1994 p.286) Center: Early space syntax analysis of a British settlement (Hillier and Hanson 1984 p.119) Right: London Axial Map (SpaceSyntax.com)

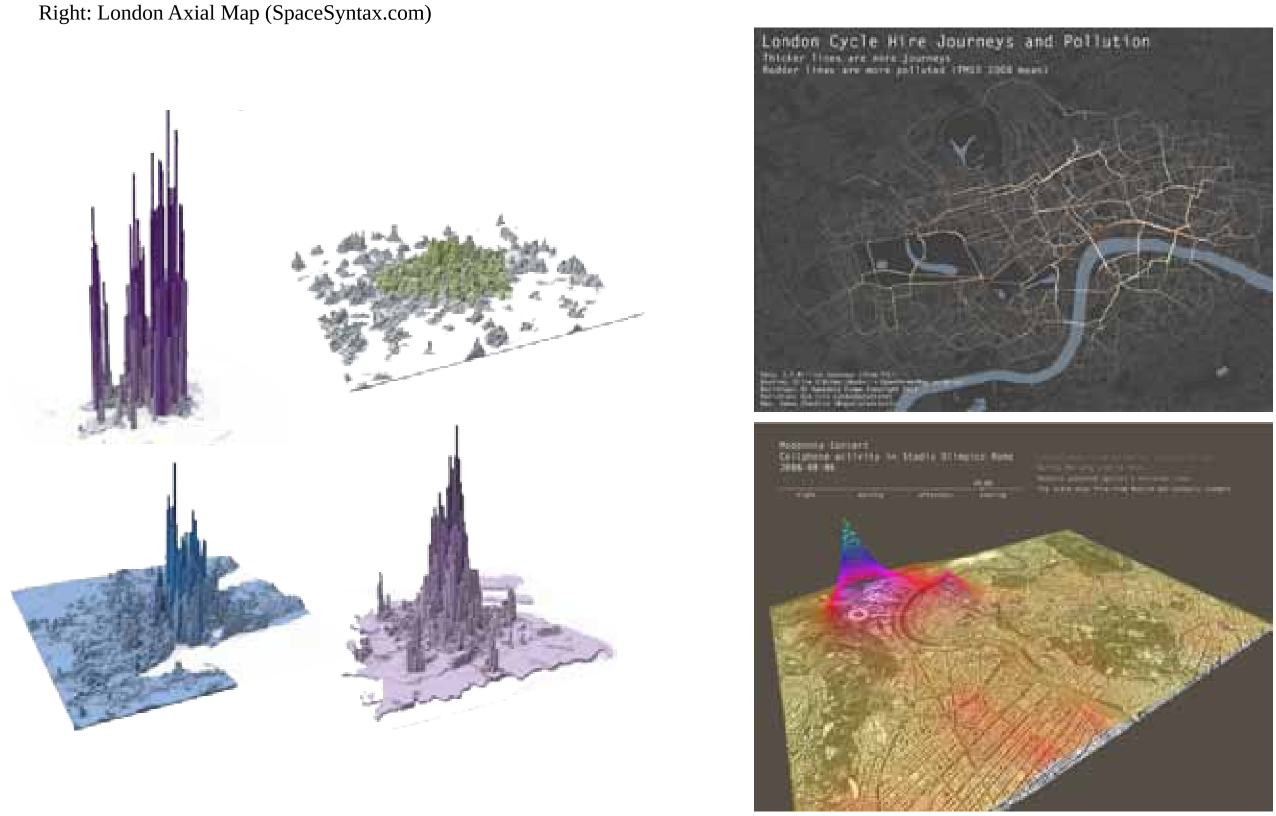


Fig.2-19 Spatial analysis techniques and large data availability have transformed urban analysis.Left: Residential density of Hong Kong, London, New York and Shanghai (Burdett & Sudjic, 2010) Right: London Cycle Hire and Pollution (Cheshire, 2012c) Phone calls at Madonna's concert in Rome (Nabian & Robinson, 2011)

It can be noted how current urban morphology is no longer a matter of mere physical transformation. The metaphors and analogies of the past have been replaced by remote sensing and big data which are readily available by a wealth of new devices used in our daily routines. So much so that one of the biggest challenges of urban research today is to tell apart the relevant data and research from anecdotic products for online consumption. The initial excitement for the new analytical possibilities boosted a plethora of maps and graphics, which became successful, more due to their appealing appearance than for the actual usefulness of their insights. As Batty and In a recent editorial[95] Batty and Cheshire described how Big Data can further dematerialize the notion of urban form and make physical description insufficient to advance in a real science of cities. The current capacity to harness and process data has revitalized concepts from systems theory for it allowed the reconciliation between planning and social sciences. What is yet to be seen is how the geography of flows can be embedded in the rudimentary planning instruments to activate propositional strategies that can effectively respond current social and economic restructuring.

95 Batty & Cheshire, 2012

2.4 Mapping European Urban Regions

A comparative analysis was drawn up with twenty four European cities and their metropolitan regions. This analysis aimed both to challenge theoretical precedents and to unveil common patterns in the urban structure and performance across all samples. Comparative research has been frequently used in urban studies due to its explanatory potential and its capacity to measure the scope for extrapolation[96]. Although other cities were considered, the final selection was based on the following criteria:

- The scope was European. Common trends can be more easily found in a pan-European study than in a worldwide research. Initially, Los Angeles and Hong Kong were included and analyzed in order to depict two extreme cases of sprawl and high density. However, it was considered redundant and not relevant to the study.
- The geographic distribution of the samples should cover different latitudes, with special attention to the densest areas of the continent.
- There is abundant data for each city and the level of information is homogeneous among them, in order to avoid gaps and bias in the analysis.
- They should present a wide range of metropolitan forms that could be related to theoretical morphological classifications (as discussed in chapter 2)
- The cities have grown along industrial expansion and have experienced the effects of the new economic model in their physical structure

The representation of the regions was a challenging task as spatial analysis would the main tool to unveil underlying patterns. The graphic language needed to be consistent so that visual comparisons could be done unambiguously and without loss of critical information. The use of satellite imagery could have been a possible approach but the boundaries of different land cover types are hard to discern in orthophotos. Instead, different cartographic datasets were selected and processed to compose three visualization modes, each one of those portraying an specific layer of analysis.

2.4.1 Representation of the cities in their regions

Land Cover

In the first mode, the arrangement of urbanized areas over the territory was highlighted, identifying the main industrial sectors but not the intensity of urban areas (fig. 2-20). Two main datasets were used: Corine Land Cover and a digital elevation model (DEM). The former was obtained as GIS vector format from the European Environment Agency data store.[97] It contains information on the spatial distribution of 44 land use types across Europe in 2006 (last update). The digital elevation model was obtained from the United States Geological Survey (USGS)[98]. It consists on models that reach a resolution up to 250 meters and has worldwide coverage. The tile mosaic that contains the information for the selected cities was downloaded using the "EarthExplorer" site of the USGS[99]. They were then processed and combined using GvSIG to provide a geographic background with natural and neutral appearance. Maps should extend well beyond the urban centers to understand how the cities relate with the broader region. Therefore, 150 by 150 km squares were delimited for all samples. Land cover and geographic layers were simplified to five categories:

- Urban areas. It includes most artificial surfaces that are part of the urban fabric. They do not include green areas or metropolitan infrastructure (roads, railway)
- Industrial zones. It covers the main industrial and commercial areas as well as large infrastructures such as airports, ports or landfills.
- Forests. It shows the relevant forests of the region
- Water bodies, including rivers, oceans, marshes and lagoons
- Topography. The areas that do not correspond to any of the previous land use types are represented by the DEM. A soft color code has been used to depict altitude. Low lands appear as light brown whereas mountain peaks are colored in white. A hillside effect emphasizes the topography.

Residential density

The second visualization set focused on the spatial distribution of population density in the twenty six urban regions (fig. 2-21). Data was available in raster format at 100 meters resolution from the European Environment Agency[100]. All samples were processed and plotted in GvSIG using a color code to differentiate four steps in residential density. The tabulations were distributed in such a way that the lowest value would portray rural zones, up to a density of 40 persons per hectare (40ppha). According to some theories[101], 40 ppha is the minimum threshold to provide urban facilities. The next category corresponds to what UK standards[102] have defined as medium density (40-60 ppha). The last two categories could be qualified as genuinely urban. They were divided in moderately dense areas, with density ranging from 60 to 120

96 Examples of urban comparative research are numerous, in this text Forman, 2008 Burdett & Sudjic, 2007 or Oswalt &Rieniets 2006 have been referred

97 www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version [Last accessed 13.10.2013]

98 www.usgs.gov [Last accessed 20.08.2013]

99 earthexplorer.usgs.gov [Last accessed 20.08.2013]

100 www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2 [Last accessed 20.08.2013]

101 Lozano, 1990

102 Cheng, 2010

ppha and high density areas, for all zones beyond the 120 ppha threshold. In this set of maps, only density and water bodies were plotted in order to provide a clear visualization of density values over a basic geographic reference.

Urban structure

Finally, the key information from the two previous analyses was overlapped to produce synthetic maps of the urban structure (fig. 2-22). Four layers were considered critical to reveal the metropolitan patterns of organization: the areas of residential concentration, the main economic zones, water bodies as geographic reference, and the transport network:

- Residential areas. Rather than plotting all residential zones, only the most important clusters were mapped. The threshold of 120 ppha was chosen as it is a value that enables the efficient implementation of urban systems such as public transport[103] or the use of combined heat and power[104] and it is accepted as a threshold to high density areas in UK standards[105]
- Industrial and main tertiary zones were mapped to highlight the relation between residential and working centers. The layer for commercial areas was obtained from the Urban Atlas cartographic dataset[106], which provides "comparable land use and land cover data for Large Urban Zones with more than 100.000 inhabitants". This dataset was used to display the transport network (fast transit roads and railways) and water bodies (rivers, channels, lagoons and oceans)

Key performance indicators

In addition to the spatial analysis, key urban performance indicators were assembled from existing reliable sources (peer reviewed studies or official agencies) for comparison and to explore the possible correlations with the morphological attributes (fig. 2-23). The nature of these indicators was varied as they indented to cover social, economic and environmental issues in synthetic parameters. Particular attention was given to those aspects which are allegedly influenced by urban form, according to mainstream theories, such as access to green spaces, average living area per person, transport or air pollution. A relational matrix was then produced from the outcomes of multiple observations.

2.4.2. Analyzing regional patterns

The twenty four urban regions were exposed to challenge previous studies of urban form (which were thoroughly discussed in chapter 2). The hypothesis was twofold: on the one hand, classic city types would be brought out and critically reconsidered; on the other hand, connections between these types and performance would be explored. The general strategy was not an original one, as comparative analysis of cities is a common tool in urban research. The exponential increase of data availability (including new cartographic datasets) provides now greater possibilities. It has also facilitated new approaches to sharpen insights on the field. Moreover, analytic techniques advance to such a pace that the state-of-the-art level has to be constantly revised and updated in the light of the newest findings.

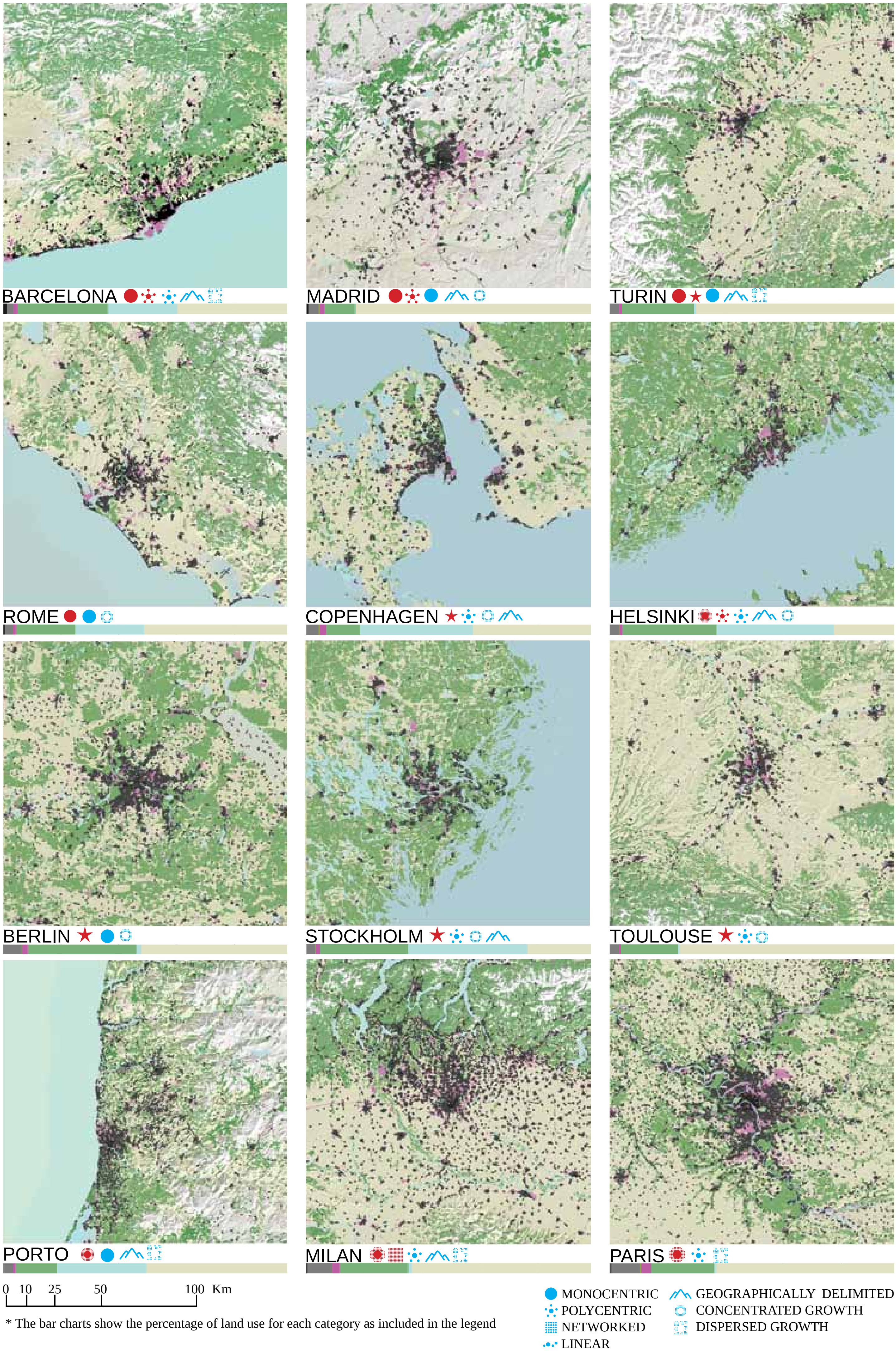
Regional structure of land cover patterns

Land cover arrangement offers the first and most straightforward means of exploration (fig. 2-20). The delineation of urbanized areas over the territory highlights the extent and shape that urban expansion has taken as determined by historical evolution and geographic constrains. Despite what may appear at a first glance, only a minor portion of land is actually urbanized in all the analyzed regions. Artificial land cover ranges from one fifth to less than one tenth of the total land. The largest city is found in Brussels, where combined industrial and urban land account for over 26% of the territory (this is still significantly lower than the 47% of urbanized area in Los Angeles, USA). London, Cologne, Liverpool and Lille are close to 20% whereas the remaining regions present urbanization levels below 15%. British and central European cities are, in general, more dispersed than Mediterranean and Baltic regions. Barcelona, Madrid, Rome or Turin can be said to be relatively self-contained as the extension of their urban areas barely reaches 7% of land. The presence of geographic features helps to explain cases such as Barcelona or Rome, where the sea and mountains acted as natural barriers that restrained extensive development. Water bodies were excluded in the percentage calculations as to avoid bias between coastal and inland regions.

Natural systems were portrayed as forests, water bodies and greenspaces due to the particular significance of these three variables in landscape ecology but also for their influence in the quality of the urban environment. Forests protect aquifers and biodiversity, whereas urban green areas are vital to ensure connectivity between natural systems.[107] In terms of relative figures, climate and soil conditions seem to be as important as the economic weight of forest industries in the preservation of woodlands. In fact, the Scandinavian regions of Helsinki and Stockholm present, by far, the largest proportion of forest land (above 50%). Only six regions have a larger ratio of urbanized areas than they have for woods: Amsterdam (16% urbanized against 9% of forest), Birmingham (13/4), Brussels (26/17), Lille (19/5), Liverpool (18/4) and London (20/8). It appears to be a consistent connection between industrial regions and the relative absence of forests, with an exception of Cologne and its surrounding Ruhr region (19% urban versus 27% woods). The urban green

103 Urban Task Force, 1999
104 Owens, 1992
105 Cheng, 2010
106 www.eea.europa.eu/data-and-maps/data/urban-atlas [Last accessed 20.08.2013]
107 Forman, 2008 p.142

Fig.2-20 Urban rregions: Land cover



* The bar charts show the percentage of land use for each category as included in the legend

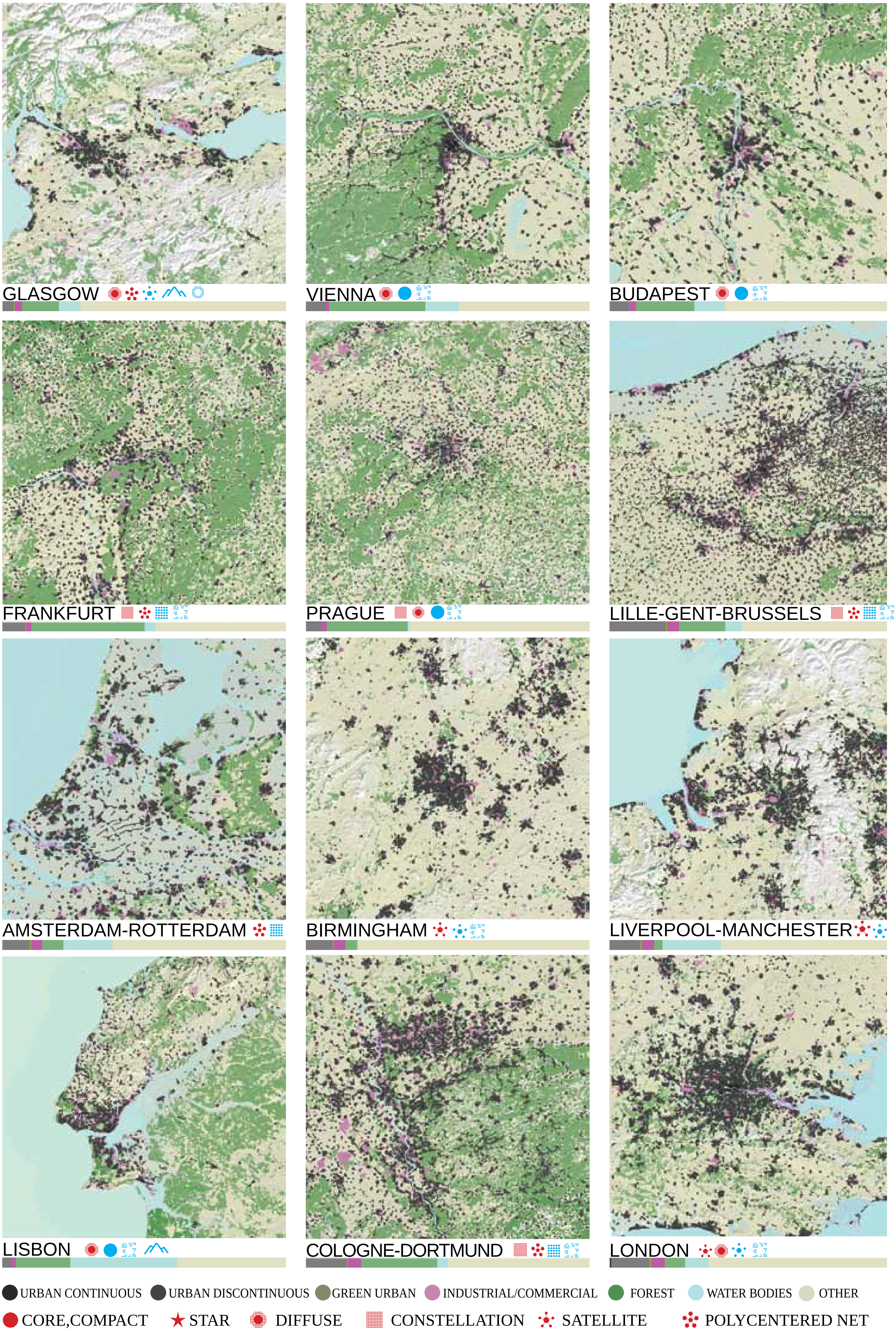
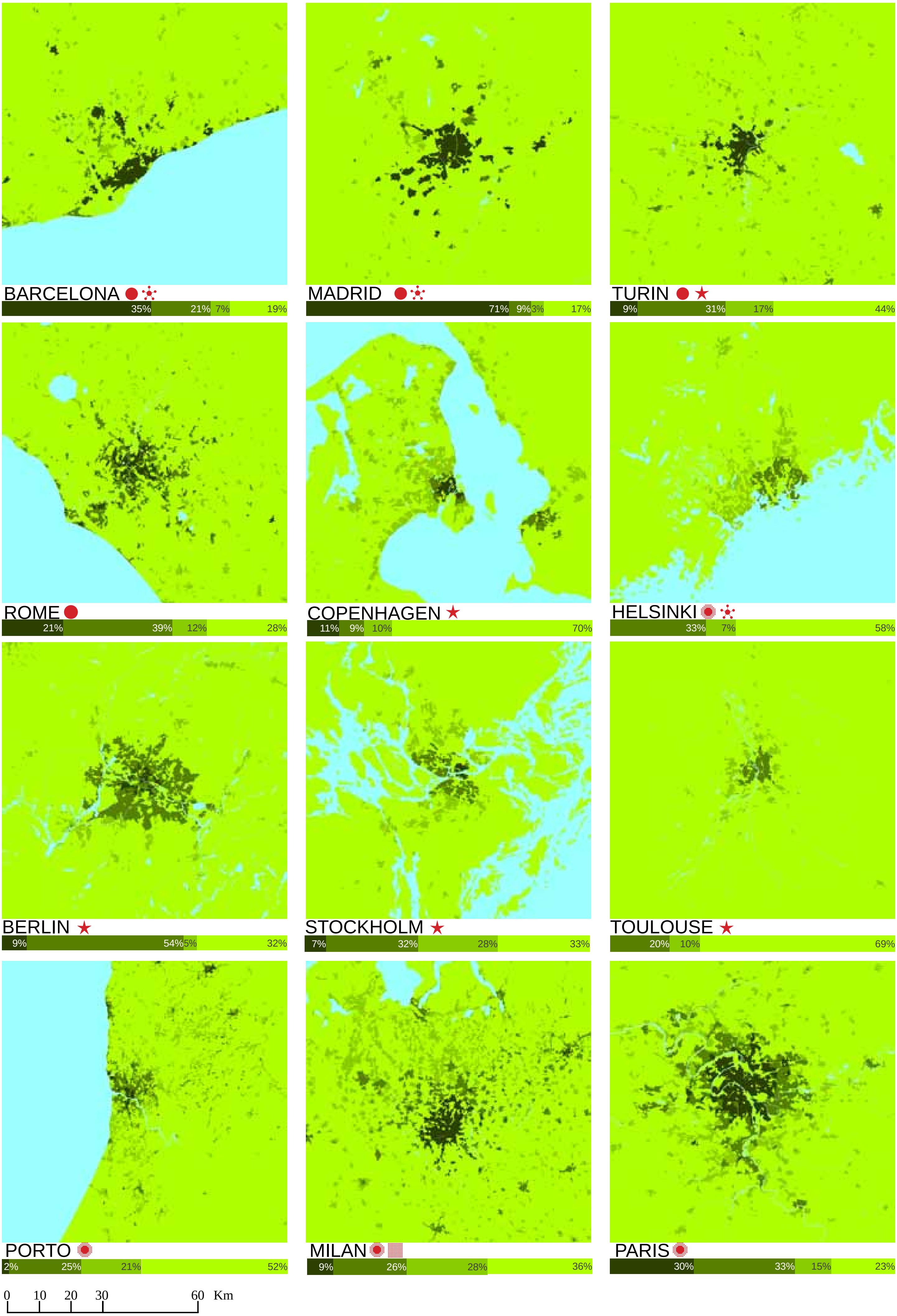

GLASGOW
VIENNA
BUDAPEST
FRANKFURT
PRAGUE
LILLE-GENT-BRUSSELS
AMSTERDAM-ROTTERDAM
BIRMINGHAM
LIVERPOOL-MANCHESTER
LISBON
COLOGNE-DORTMUND
LONDON
URBAN CONTINUOUS
URBAN DISCONTINUOUS
GREEN URBAN
INDUSTRIAL/COMMERCIAL
FOREST
WATER BODIES
OTHER
CORE,COMPACT
STAR
DIFFUSE
CONSTELLATION
SATELLITE
POLYCENTERED NET

Fig.2-21 Urban regions: residential density



* The bar charts show the percentage of population living in each density range (note that it does not reflect the area but the population in each category)

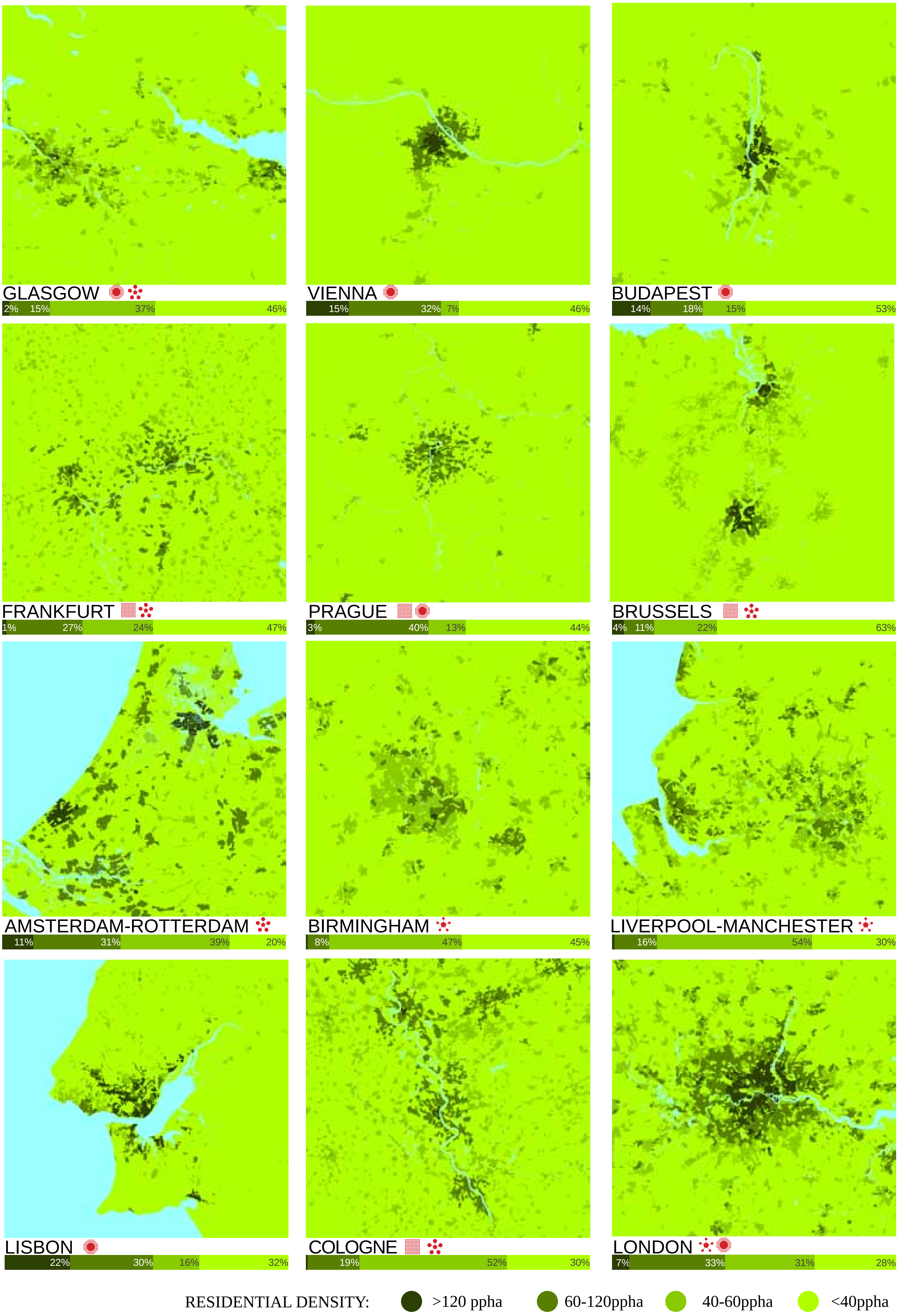
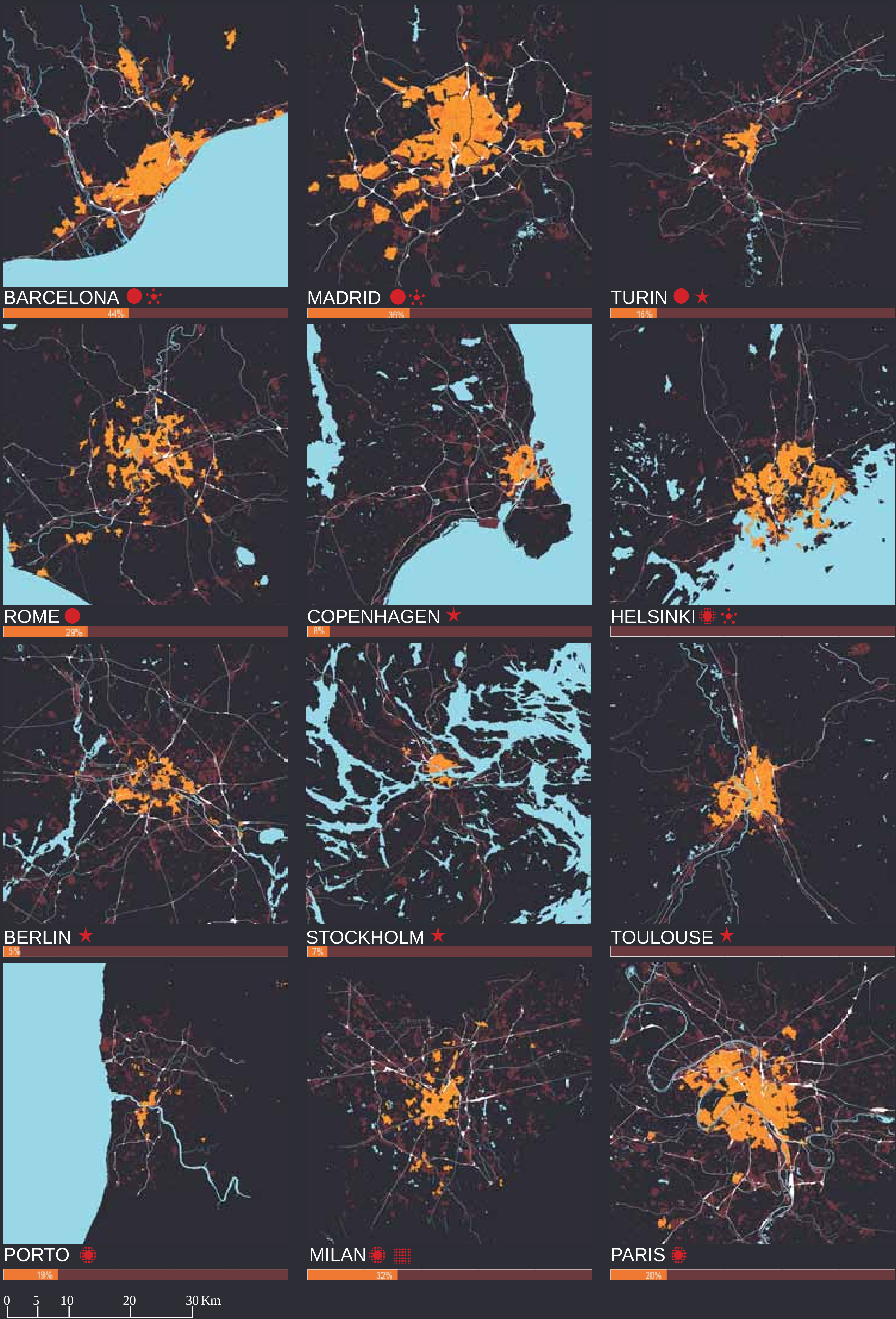
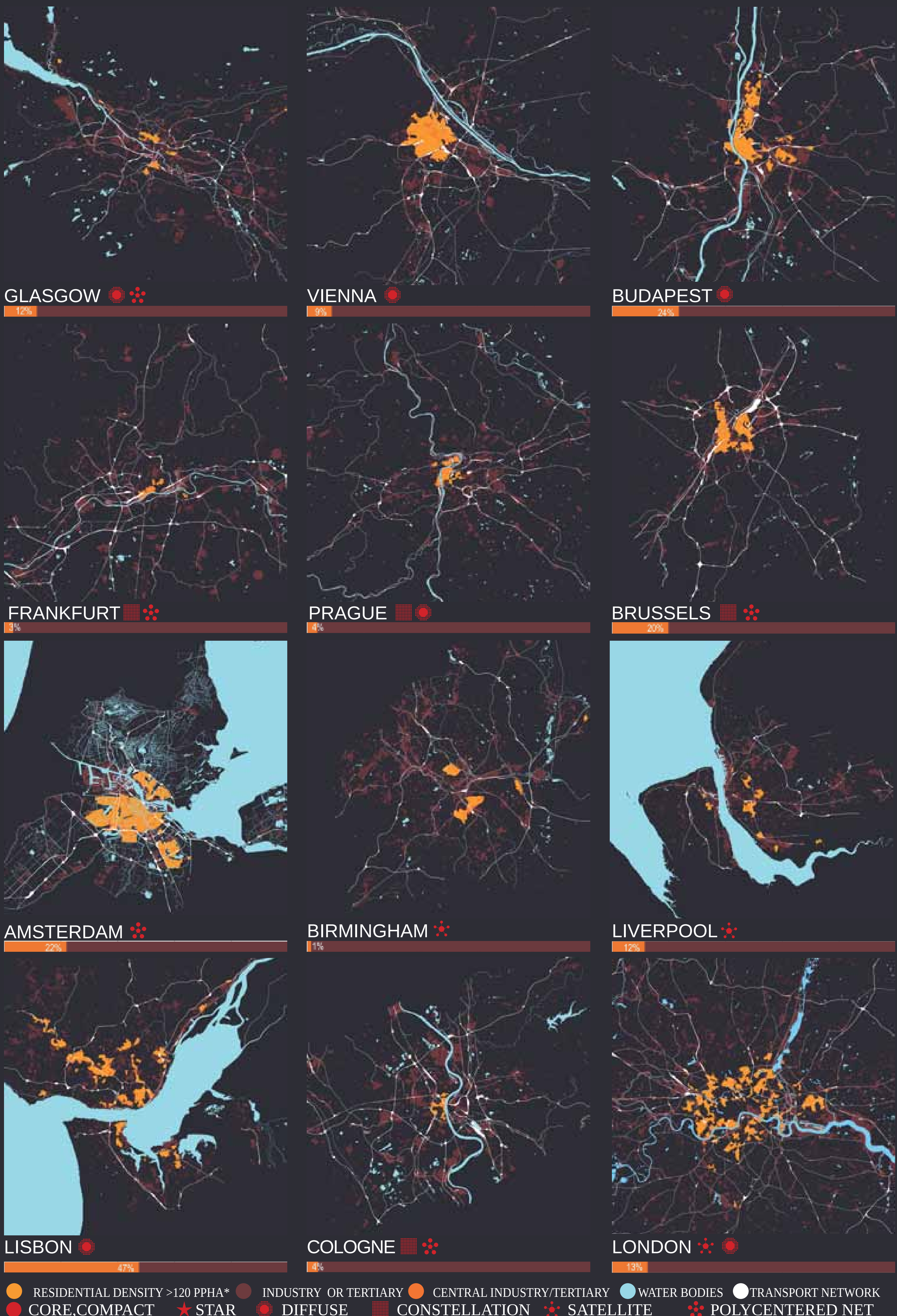

GLASGOW
2% 15% 37% 46%
VIENNA
15% 32% 7% 46%
BUDAPEST
14% 18% 15% 53%
FRANKFURT
1% 27% 24% 47%
PRAGUE
3% 40% 13% 44%
BRUSSELS
4% 11% 22% 63%
AMSTERDAM-ROTTERDAM
11% 31% 39% 20%
BIRMINGHAM
8% 47% 45%
LIVERPOOL-MANCHESTER
16% 54% 30%
LISBON
22% 30% 16% 32%
COLOGNE
19% 52% 30%
LONDON
7% 33% 31% 28%
RESIDENTIAL DENSITY:
>120 ppha
60-120ppha
40-60ppha
<40ppha

Fig.2-22 Urban strucures



The bar charts show the percentage of industrial and commercial areas which are within 1,000m of residential clusters (residential density higher than 100 ppha)



* Core residential densities (light orange areas) for Toulouse and Helsinki were plotted as 60ppha in their respective maps as those cities never reach 100ppha

Fig.2-23

European Cities

Comparative Data

	POPULATION[1] x1,000	NET DENSITY[1] ppha (urbanized area)	CO_2 EMISSIONS[2] Tons/person year	POLLUTION[3] micrag NO_2/m³ air (annual avg.)	AIR QUALITY[4] people dissatisfied (%)	NOISE[4] people dissatisfied (%)	GREEN AREAS[4] people dissatisfied (%)
AMSTERDAM	10,642	50	6.6	41	41	48	16
BARCELONA	5,445	65	4.2	48	76	80	42
BERLIN	5,310	35	6.5	28	49	59	16
BIRMINGHAM	9,090	43	N/A	N/A	N/A	N/A	N/A
BRUSSELS	10,282	23	7.5	30	76	66	23
BUDAPEST	4,432	29	5.8	29	92	85	43
COLOGNE	14,400	45	N/A	N/A	N/A	N/A	N/A
COPENHAGEN	3,037	31	5.4	25	68	56	12
FRANKFURT	7,447	41	13.7	18	N/A	N/A	18
GLASGOW	3,915	42	8.8	40	57	53	10
HELSINKI	1,507	21	7	23	42	48	11
LISBON	3,465	45	7.5	30	85	79	45
LIVERPOOL	10,620	44	N/A	33	89	N/A	N/A
LONDON	15,592	50	9.6	42	77	72	13
MADRID	5,940	59	6.9	28	85	84	21
MILAN	8,842	44	N/A	N/A	N/A	N/A	N/A
PARIS	12,082	51	5.2	40	77	74	17
PORTO	3,622	43	N/A	N/A	N/A	N/A	N/A
PRAGUE	3,397	28	9.3	30	74	76	23
ROME	4,950	63	3.5	40	N/A	84	31
STOCKHOLM	2,115	30	3.6	16	71	65	9
TOULOUSE	1,890	28	N/A	N/A	N/A	N/A	N/A
TURIN	3,802	52	N/A	57	83	69	14
VIENNA	3,892	26	5.19	23	41	52	15

GREEN AREAS[5] m² public/person	SKILLS[6] Highly qualified residents (%)	JOBS[7] Unemployment (%)	WEALTH[6] GDP (thousand €/person)	AVG. DWELLING SIZE[5] m²/person	TRAVEL TO WORK[7] Non motorized (%)	TRAVEL TO WORK[7] Public Transport (%)	TRAVEL TO WORK[7] Private Car (%)
35	33	5.1	46.5	34	22	23	N/A
4	N/A 48	22.1	29.1	32	29	20	50
27	28	8.3	23.7	38	18	32	50
11	18	6.6	28.6	N/A	N/A	17	72
13	N/A	10.7	48.0	36	7	18	74
43	24	9.2	22.7	21	N/A	N/A	N/A
43	21	5.4	36.2	39	16	22	61
52	28	7.9	38.9	44	24	N/A	N/A
18	26	4.5	44.1	38	16	21	61
14	26	4.6	28.1	N/A	N/A	N/A	N/A
146	39	6.3	41.1	34	15	34	N/A
4	22	12	29.8	N/A	19	34	47
15	17	9.8	20.8	N/A	N/A	18	69
12	33	9.1	38.9	40	22	38	40
7	N/A	19	32.8	30	17	42	28
15	20	7.5	45.5	38	13	20	66
9	50	8.5	46.0	35	N/A	N/A	N/A
12	19	16	21.0	N/A	21	27	52
83	42	4.6	26.2	18	7	N/A	N/A
15	18	10.8	36.0	35	9	20	70
96	24	6.8	41.1	41	17	34	49
3	36	8.8	33.0	38	11	7	81
22	17	7.5	34.7	35	12	15	72
11	17	4.1	40.6	46	N/A	N/A	N/A

Data: 1 Regional data based on spatial analysis 2 Kennedy et al, 2011 3 EEA, 2009 4 Gallup-Hungary, 2010
5 Urban Audit, 2004 6 Ecotect Research and Consulting, 2007 7 Eurostat, 2013

has a much lower presence as it does not reach 1% of the region in any of the examples. However, the location of parks and green spaces within built areas offers important benefits to the urban population as well as it enhances surrounding natural systems[108]. London and Liverpool have the largest sum of green areas among all regions (over nineteen and sixteen thousand hectares respectively, which get close to 1% of the land in both cases). However, if these figures were analyzed as proportion of green to urban extent, Copenhagen and Stockholm would then be the greenest cities, in spatial terms, with their parks accounting for about 7% of the built area. The fig. 2-23 shows, in turn, the ratio of green areas per inhabitant. In this case, Helsinki shows the most favorable figure (146m² per person) followed by Stockholm (96) and Prague (86). Irrespective of the measure units, some cities are consistently at the bottom of the list. Barcelona presents the poorest records, both in spatial terms (0.3% of the built area) and relative to population (4m² per person), closely followed by Toulouse (0.6% and 3 respectively).

The student of the city would be hardly satisfied with quantitative analysis. As explained in the previous paragraphs, classic morphological classifications aimed to typify cities in general categories, such as core, star, diffuse, satellite or constellation. These classifications were based on more or less consistent analogies derived from the visual observation of maps or satellite images. The continuous evolution of urban systems has made some of the initial types obsolete in a short period and has blurred the boundaries among the others. A recent study on South European metropolitan regions has proposed up to nine classes, based on the combination of their core spatial structure and the urban expansion they experienced since the ninety seventies[109] (table 2-2). A polycentric system of contained and compact cities was officially declared the desirable urban form by the European Spatial Development Perspective (ESDP)[110] and the Green Paper on the Urban Environment[111] in the nineties.

Table.2-2 Metropolitan Configurations according to Font et al (Font,2007)

Spatial Structure	**Dominant attributes**	**Type of expansion**	**Examples**
Monocentric	Geographically delimited	Concentrated growth	*Genoa*
Monocentric	Geographically delimited	Dispersed growth	*Naples*
Monocentric		Concentrated growth	*Madrid*
Monocentric		Dispersed growth	*Lisbon*
Polycentric	With a dominant centre	Concentrated growth	*Montpellier, Bologna*
Polycentric	With a dominant centre	Dispersed growth	*Barcelona, Milan*
Monocentric	Dual	Dispersed growth	*Porto*
Networked		Dispersed growth	*Veneto*
Linear		Dispersed growth	*Donosti-Bayonne*

Table.2-3 Metropolitan Urban Form using classic types

Core Structure	**Trend**	**Examples**
Core, Compact	Satellite	*Barcelona, Madrid*
Core, Compact	Star	*Turin,*
Core, Compact	Core, Compact	*Rome*
Star	Star	*Berlin, Stockholm, Copenhagen, Toulouse*
Diffuse	Diffuse	*Paris, Porto, Lisbon, Vienna, Budapest*
Diffuse	Satellite	*Helsinki, Glasgow, London*
Diffuse	Constellation	*Milan, Prague*
Satellite	Satellite	*Amsterdam, Birmingham, Liverpool*
Polycentered Net	Constellation	*Frankfurt, Lille,Cologne*

Table.2-4 Metropolitan Urban Form using Font et al categories

Spatial Structure	**Type of expansion**	**Examples**
Monocentric	Concentrated growth	*Madrid*
Monocentric	Dispersed growth	*Turin, Porto*
Monocentric	Concentrated growth	*Rome, Berlin, Madrid*
Monocentric	Dispersed growth	*Vienna, Budapest, Prague, Lisbon, Turin, Porto*
Polycentric	Concentrated growth	*Helsinki, Stockholm, Toulouse, Glasgow*
Polycentric	Dispersed growth	*Barcelona, Milan, Paris, Birmingham, Liverpool, London*
Networked	Dispersed growth	*Frankfurt, Lille, Amsterdam, Cologne*

108 Ibid, p.165

109 Font, 2007

110 Comittee on Spatial Development, 1999

111 CEC, 1990

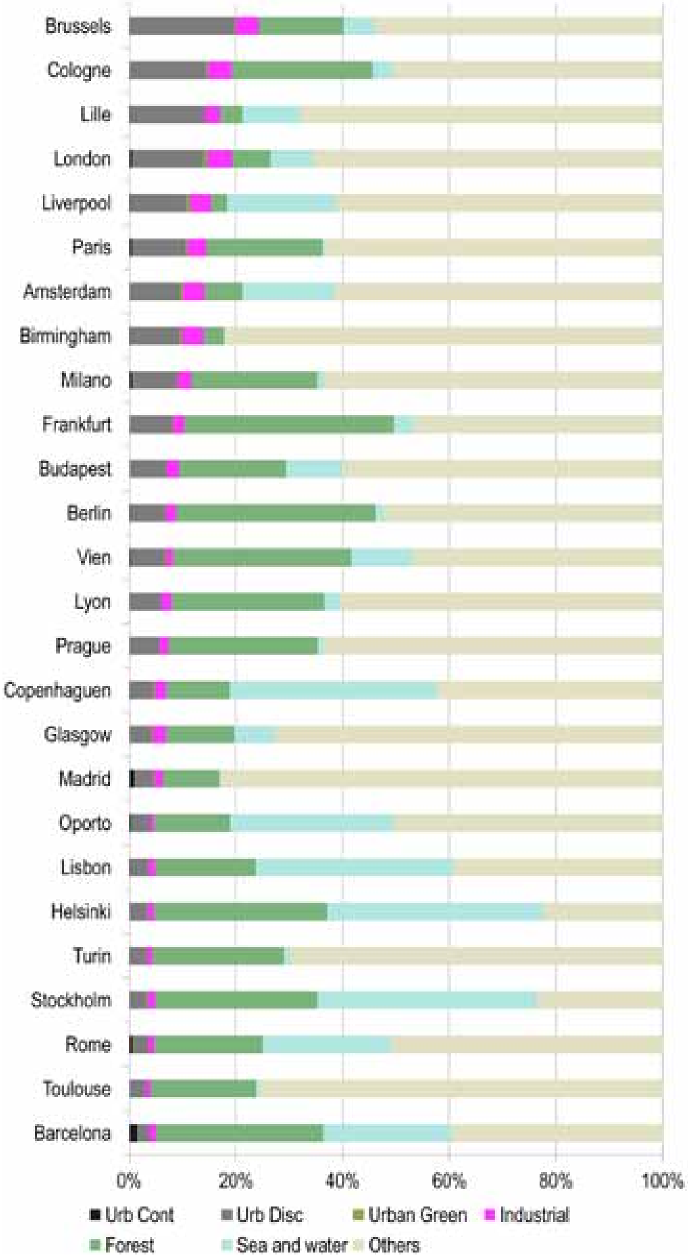


Fig.2-24 Land use break down of the urban regions

The twenty four urban regions were classified according to two different criteria sets. The first one intended to reflect classic categories, as assembled from selected literature in chapter 2. As pure forms are unlikely to define the dynamic nature of cities, types were defined by two levels: the core structure and the prevailing trend. The former describes the consolidated urban form by the end of the twentieth century and the latter intents to reflect the trend of current and future transformations. The second classification criteria borrowed the morphological types described in table 2-2. The objective of this exercise was to explore and test the validity of this kind of generalizations. If they were consistent, it might allow the extrapolation of certain findings from specific case studies to other similar regions. Both classifications are illustrated in figure 2-20 and tables 2-4 and 2-5.

This analysis highlighted the inability of a single term to accurately define current urban forms, which have, in fact, an evolving nature. A two-tier definition offers a greater capacity to reflect, both the core spatial structure, which is normally more stable, and the dynamic urbanization patterns, that are subject of greater variations in shorter periods. Three main spatial structures can be used to characterize European cities: Monocentric, Polycentric and Networked. Each of those has recently evolved in either a concentrated or dispersed mode. This simple classification would cover the twenty four urban regions of this study.

Regional population distribution

The land mosaic analysis has shown the arrangement of built areas and natural systems but did not reveal the intensity of urban zones. Density maps contain further information about spatial aspects and living conditions of the regional population. Variations in density patterns may result in a completely different built environment, even for cities that fall in the same morphological typology. Quantitative parameters make classification easier as once the threshold criteria has been established, the allocation of samples can be automatically done. In this case, the degree of compactness or dispersion was analyzed for each region. The criteria to define a case as compact or dispersed would be given by the proportion of inhabitants that dwelled at the core city (more than 120 ppha) and those who lived in areas of low density (<40ppha).

Six out of the twenty four metropolitan regions[112] do not reach the density threshold of 120 ppha in any part of their territory: Cologne, Liverpool, Birmingham, Toulouse, Helsinki and Lille (fig. 2-25). The latter city is also the case study with the largest proportion of population living in low density areas (78% living in zones with less than 40 ppha). Copenhagen, Toulouse and Brussels fall close behind, all them with more than 60% of their residents living in “rural” zones. In the opposite extreme, Madrid and Barcelona have the highest ratio of population living in the densest sectors (71% and 53% respectively), followed by Paris, Lisbon and Rome, whose ratios of residential concentration range from 30 to 20%. The average for all the selected samples illustrates a clear imbalance between the two poles, as three times more people are currently living in areas of less than 40 ppha (38% of the population) than they are in areas of density above 120 ppha. This may be an outcome of urban evolution or it may express a preference of European citizens for suburban and rural environments. According to these results there is not an apparent connection between size and density arrangement.

112 The two further regions are explained by the addition of Lyon and the separate analysis of Brussels and Lille

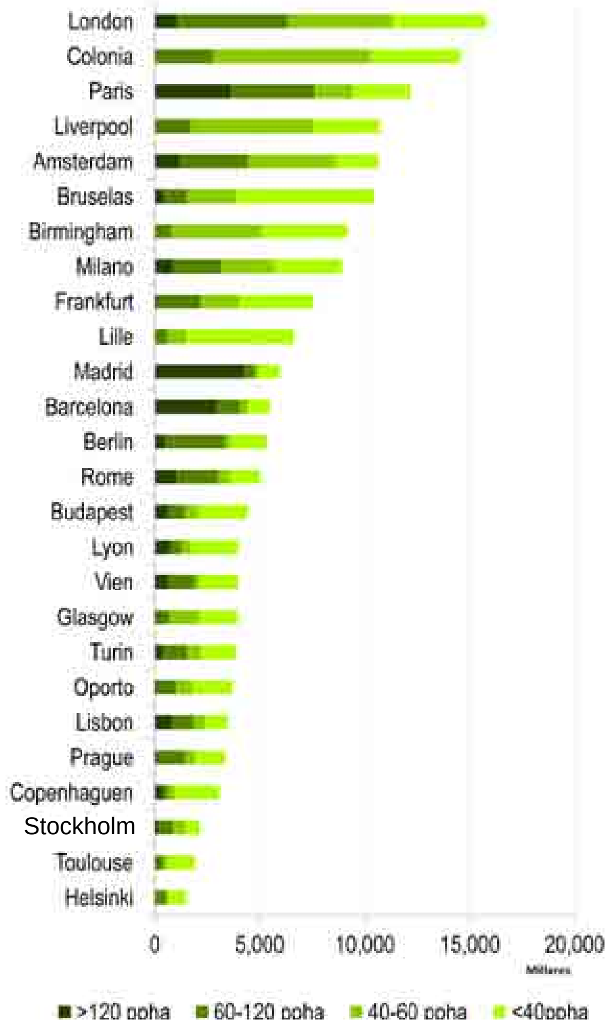


Fig.2-25 Residential density distribution. Total people living in areas of each density range

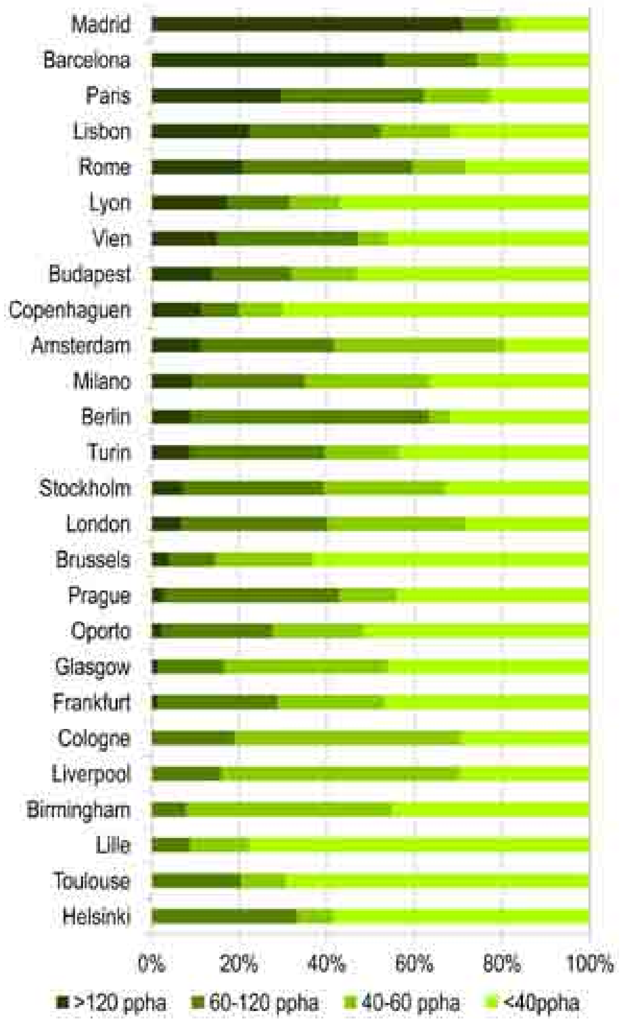


Fig.2-26 Residential density distribution. Percentage of population living in areas of each density range

The peak density is typically located at the core of the built up area and it gradually decreases the further it gets from the city centre. In polycentric and networked regions, second order towns may spread all over the territory. These are clearly highlighted from the rural background as it can be seen in cases such as Frankfurt or Cologne in figure 2-21. In general, the patterns that were intuitively inferred from the land cover observations will be confirmed by the display of density data.

Synthesis of the Urban Structure and Land Use

Land cover maps differentiated between industrial and commercial land use from other built up areas. There were no comments on that as clear patterns were not unveiled. However, in this set of analytic maps, the industrial zones were overlaid to the core residential areas. The main objective was to compare the relative position between the main areas of employment and habitation. As it has been shown in previous sections, the mixture of uses is meant to induce a reduction in the need of travel, as more jobs are available close to residential sectors. Spatial analysis was undertaken to calculate the proportion of commercial and industrial land that lies within 1,000 m distance (i.e. “walkable” distance) to a zone with a residential density higher than 100ppha (fig. 2-22). The migration of industrial centers to the periphery started in the ninety seventies and it was furthered by new

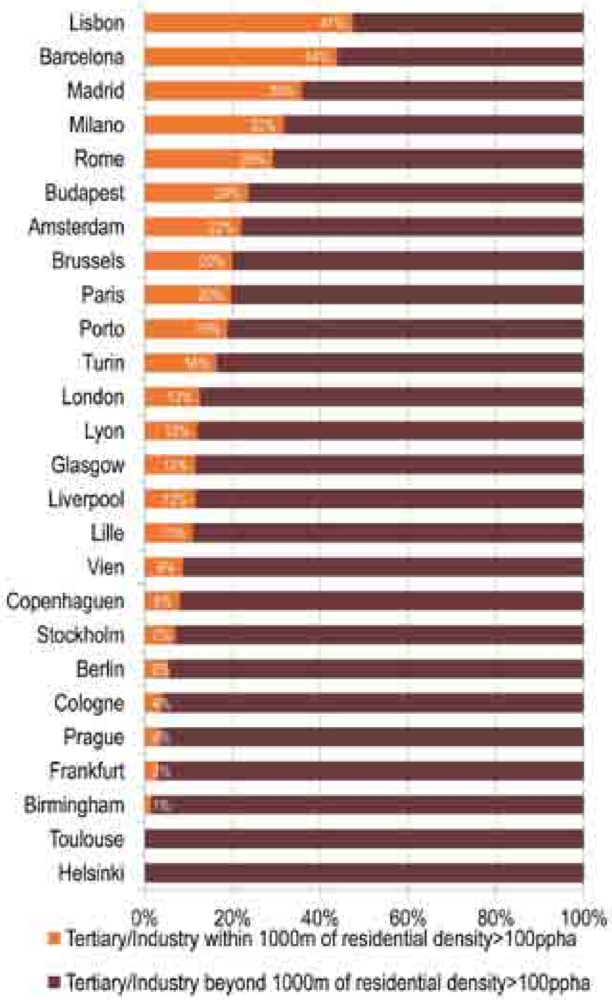


Fig.2-27 Urban Structure: Percentage of tertiary within 1000 m to a residential area of density higher than 100ppha

communication technologies, cheaper land prices and spatial availability on the suburbs. This was followed by the relocation of tertiary centers, which became specialized malls that served to the increasing suburban population by locating close to the main transport arteries. The traditional Mediterranean cities were not immune to this trend, thus endangering their inner city street life.

The data analysis still reflects the stronger mixture of activities in Mediterranean cities, as the top five analyzed samples that showed a greater integration of commercial and industrial activities in the urban fabric were Lisbon, Barcelona, Madrid, Milan and Rome (fig. 2-27). The proportion ranged from 47% in Lisbon to 29% in Rome. This is well above the average for all samples, which barely reaches 16%. At the bottom of the list were those cities which lack dense residential sectors (Helsinki, Toulouse), followed by those with a higher degree of dispersion. Birmingham, Frankfurt, Prague or Cologne did not reach a 5% ratio of integration. In this case, linear or elongated residential structures seemed to offer more possibilities for interaction than diffuse or concentric cities.

2.4.2 Key Performance Indicators and Urban Form

A taxonomic designation of urban form can be used for basic purposes, such as cataloguing or grouping or it can be assumed ambitious values, such as the capacity to extrapolate common attributes and derived processes within types. The latter case is frequently taken for granted when different urban models are discussed. Thus, commentators may articulate a highly convincing discourse on the benefits, say, of the compact city model, assuming that observations from several case studies can be generalized to all cities that fall under that category. However, overgeneralization, though useful for communication purposes, may be deceiving as there are various ways in which, for instance, a city can be defined as compact, and not all of them may necessarily lead to a similar performance range. It is necessary to find unambiguous definitions in order to increase the level of accuracy in this kind of extrapolations. Quantifiable attributes such as those analyzed in the previous paragraphs offer that level of precision but they have to be applied at consistent resolution levels. For instance, regional density is not comparable to metropolitan density as they refer to completely different scales.

The selection of key social, environmental and economic indicators for the twenty four samples (fig. 2-23) allows, not only to draw direct comparisons among the urban regions but also to identify correlations between these variables and spatial attributes at regional scale. The results from this analysis were summarized in figure 2-28, in the form of a matrix, which (like in previous cases) highlights the potential connections in a graphic way. Although the correlations were relatively weak (they are shown in the graph) and the number of observations was limited to the twenty four samples, some patterns emerged:

- The rate of CO2 emissions per capita tends to increase in regions with a greater ratio of population living in low density zones and where built up area spills further out. Conversely, it decreases when population lives more concentrated and there is a greater overlapping of working and residential areas. This trend confirms common wisdom and it is probably closely related to commuting patterns, which will be further explored.
- In contrast, net regional density and the proximity between working and living areas seem to have a negative impact in air pollution. This is confirmed by NO2 emissions and the perception of air quality in surveys. In addition, predominantly rural regions also present lower emissions.

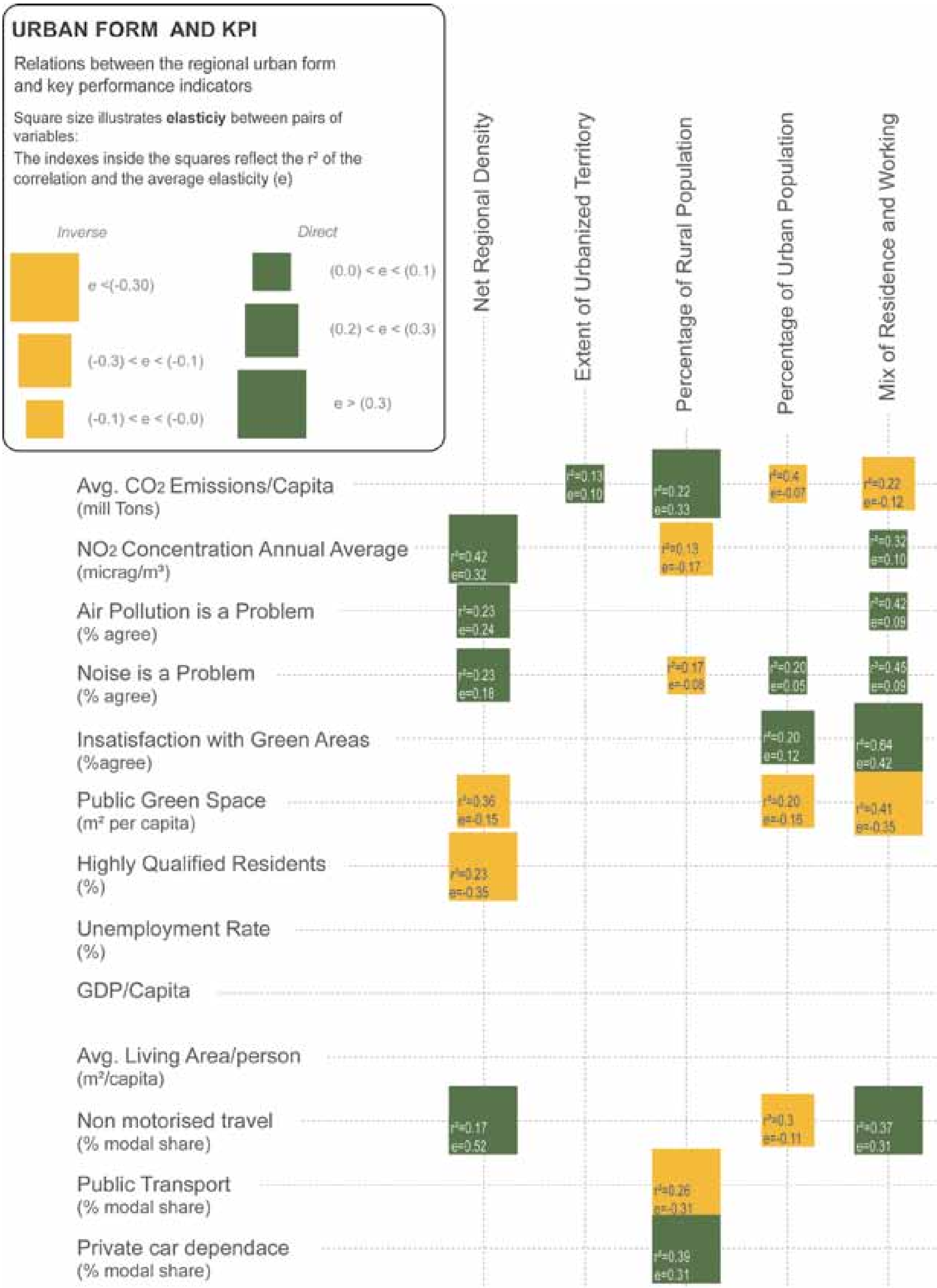


Fig.2-28 Urban Form and Key Performance Indicators

- A similar pattern was identified regarding noise and green areas. Residents of dense, urban and mixed regions reported a higher level of dissatisfaction with both noise and the quality of urban parks. This was confirmed when the ratio of green area per capita was accounted.
- The only socioeconomic variable that could be said to be in correspondence with the analyzed spatial parameters was the percentage of skilled population, which tended to increase in the most populated urban systems. GDP, unemployment rates or the average living area per person did not show any relation with formal aspects.
- Finally, non motorized travel (walking and cycling) seem to benefit from denser and mixed environments, whereas having a large proportion of residence in low density areas seem to induce greater use of private car. Transport issues are being discussed in detail in the corresponding chapter.

2.5 Shifting notions of ideal form

The historic events and cultural priorities of a society can be revealed by the analysis of the urban form. When spontaneous and irregular settlements were complemented with planned extensions and new towns, a new geometric order emerged. Thus a first classification of urban morphology could simply differentiate between planned and unplanned cities[113]. These two categories would provide information about the origin of a settlement, whether it was the result of casual aggregation or the expression of a preconceived idea. In any case, there was be logic behind the arrangement of plots, roads and buildings that could be discovered trough some morphological analysis. A characteristic order can be found out of the chaos of the medieval city[114] like there are variations and deformations in the regular grid. The understanding of city form implies the discernment of the reasons that shaped the city in the way it is. Planning uses that knowledge to implement policies, designs and strategies which are possible, feasible and considered beneficial to common goals. The importance of morphological studies resides on the capacity to represent the urban phenomena, to the extent that the differentiation between the mapped form and the actual city is blurred and urban analysis is misleadingly replaced by the analysis of the visual form. This is pointed by the aphorism “The map is not the territory” (attributed to Korzybski[115]) which emphasizes that the representation of an entity is not the entity itself.

Speculation on ideal forms started with the first planned cities but it would be reasonable to assume that the simplicity of the grid for surveying and allotment purposes did not raise much discussion in ancient Roman and Greek towns. Military engineers in the Renaissance found stronger incentives (gunpowder being a considerable one) to reconsider the outer shape and internal street layout of walled enclosures and defensive bastions. Likewise, utopian philanthropists reacted against the evils of the paleothecnic age. Most of these and other similar examples, gave way to proposals of small communities and colonies that were to prosper quite independently, far from existing cities.

There is little use for theorizing on ideal city form in Europe today, as cities have been already built in their majority[116]. The capacity to implement radical transformations or to propose new towns is impractical on economic and social grounds. Unless unforeseeable catastrophe, western cities will not need to undertake major development programmes and only partial retrofit operations may be sufficient to respond to the demographic needs of the next decades. For good or ill, the city’s size may remain stabilized for the first time since Industrial Revolution. Therefore any improvement in urban performance has to consider the present reality and act by providing new attributes to existing fabrics. This is a challenging task, as never in the past have cities been as large and complex as today. Luckily, the advance in knowledge and analytical instruments in the last fifty years allows being optimistic about the chance to provide a proper response to the difficult tasks ahead. A new approach to urban analysis is underway in which greater cross-disciplinary collaboration will be required to decipher the multiple flows that operate within the urban milieu. However, there are some boulders on the trail: experience from past research has shown how cities stubbornly adopted models of development that went against urban and environmental welfare. Economic priorities established the agenda and collective decisions regarding lifestyles (car ownership, garden living) eventually determined the form that cities adopted in the moments of maximum growth. Countercurrent movements emerged every time that the harm became apparent, proposing healing alternatives and measures to prevent further damage. Muratori and his followers reacted to halt the bulldozing of historic centres by modern planning ideas, which had likewise come forth as solution to ameliorate slums and overcrowding. Similarly, decentralization and dispersal has become one the main issues today but it was deemed a legitimate objective for Howard or Unwyn, to fight the appalling hygiene of the industrial city.

The answers to today´s problems may turn problematic themselves within a short interval, with the aggravating factor that planning decisions are exposed to long delays before action is taken, and perhaps the circumstances that originated those decisions have changed substantially. In addition, decision makers are more receptive to absolute and clear statements than to fuzzy or hypothetical argumentations. Policy oriented research must show determination and use

113 Kostof 1999 p.43
114 Marshall 2009 p.81
115 Ponte, 2011

116 As this statement may prove wrong for the Southeastern Asia and other developing areas where urbanization pace has experienced an unprecedented acceleration in the last decade.

strong terms to cause an impression, although this may lead to overestimation and overgeneralization. The current focus on compactness and densification[117] demonstrates how a highly complex problem can be reduced to a single variable (density) for the sake of easing decisions (in this case, to increase density). This brings out the question whether the form of the city is still a pertinent perspective today and, if it is, whether it is wise to qualify it as bad or good without any further conditions.

Kevin Lynch affirmed that although questions about "good city form" may be naive, because too many factors are beyond control, when values lay "unexamined, they are dangerous"[118]. The analysis of the form must avoid absolute qualifiers about goodness or badness but it is still necessary to visualize the relational flows of the city to extract, at least, relative dimensions of performance. In the previous review, it has been demonstrated why the understanding of form must comprehend both the physical and the immaterial components. Built fabric, transport networks and the public realm are only activated when energy, traffic, financial or social flows are in motion. It is then reasonable to conjecture that some physical attributes may determine the loads in the flow. For instance, a large building requires a greater energy supply than a smaller version of the same characteristics. Similarly, a shopping mall may pull in more visitors than a newsstand and therefore it may create denser traffic. If these hypotheses are validated, then it would be possible to modify the flows by intervening on the physical structures. This is close to the idea behind linear systems theory and it may be acceptable for simple hypothesis. However, the speculative enquiry will quickly build on more complex relations whose solution is not nearly as evident as in the previous examples. The correlation between urban form and travel behaviour is a typical example. Numerous studies have found connections between density and travel demand[119]. It has been argued that higher density reduce the distance between people and activities (jobs, leisure, commercial...) so that daily trips are shorter and can be done on foot or by public transport, which becomes more efficient. However, discrepant reports have found evidences that question the veracity of such statements[120]. The divergent lines have used surveys to demonstrate that the coincidence of dense housing and working centers does not necessarily implies a reduction in travel, as people may find more convenient to live or to work somewhere else, and they may even increase their trips for non working purposes. Moreover, travel pattern surveys typically consider multiple variables to extract correlations, this includes social (age, gender, jobs or unemployment ratios), economic (fuel prices, household income...) environmental (density, distances, urban form...) and even urban governance (public transport policies, pedestrian areas...) factors. This example illustrates how easily the analysis of urban flows builds in complexity and how contradictory conclusions for the same question can be justified just by stating different priorities.

To overcome the maze of intervening variables, traditional studies have put forward metaphors and abstract terms to synthesize formal attributes, such as "Megalopolis", "Metapolis" or "Ecumenopolis". More recent formulations have applied more objective terms: compact, dense or diffuse are usually employed to describe cities, despite the ambiguous meaning of such descriptors. The notion of scale is blurred and specific cities emerge as archetypes of urban form. The cosmopolitan centres of New York, Barcelona or Hong Kong are typically referred to as the positive side of compactness and compared to the endless suburbs of Houston, London, Sao Paulo or Mexico DF, which depict the waste of land and the irrational growth. However, a new analysis will reveal how territory has not been immune to the presence of dense, compact nuclei and, as if gravitational forces were applying, peripheral areas have experienced intense development that seems proportional to the constrains in the core city. It is very difficult to explain the growth of Shenzhen in the last decade without the neighbouring Hong Kong or the development of former rural Catalonian villages without Barcelona. The modern metropolis has to be described in relation with its region as there are few towns and cities that are not part of a broader urban constellation (either as core or satellite). Only very small and remote rural communities could be realistically considered in isolation and, in developed regions, they would have the character of mere anecdote. Polycentrism has been widely discussed in literature[121] and there is broad consensus about the convenience of applying the concept to the analysis of current cities. It further emphasizes the dynamic, rather than static, nature of urban activities, which are described by the aforementioned flows. Compactness or density will not reflect the reality they are meant to portray unless they are presented in multiple scales and accompanied by temporal dynamics: "the whole issue lays in the measurement of time with space"[122]

117 For instance Urban Task Force 1999
118 Lynch 1981, prologue
119 Newman and Kenworthy 1989 is perhaps the most widely known
120 Gordon and Richardson 1997
121 from Gottmann 1961 to Hall and Payne 2006
122 Solá Morales, M. 1986

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Fig.3-1 A good city form in the Renaissance, prepared for warfare. Palmanova, Italy (source: Kostof, 1991)

CHAPTER 3

SUSTAINABLE CITY PARADIGM AS A MATTER OF FORM

3.1. A good tree cannot bear bad fruit[1]

"What is this city that we dare to call good or bad? How can we describe it in ways that different observers will confirm and which can be related to values and performance? This simple step conceals unseemly difficulties"[2]

In his "Good City Form", Kevin Lynch aimed to elaborate a theory on the performance of cities, based on the study of urban form. The text was preceded by this warning about the complexity of such task. The question of goodness as related to city performance was added to the unsettled issue of defining the form of towns, which has been extensively discussed in the previous chapter. Notwithstanding the subjectivity and rhetoric that can blur the notion of performance, its thorough examination is necessary, both to clarify assumptions and to dispel ill informed myths. This chapter addresses the evolving nature of good and bad urban performance associated with shifting priorities in the formation of the current metropolis and how it has been consistently linked to morphological aspects.

The objectives or attributes that are deemed desirable for human communities are, essentially, dependant on the social context. Cross-cultural values or the economic situation of the region can determine a different notion of performance. It is important to acknowledge this as disregard for differential factors can result on the imposition of uniform standards to be pursued at all cost. A clear example comes from the general adoption of Western values in "developing" and emerging cultures, sometimes in stark contrast of their traditions. Likewise, collective priorities may differ from individual preferences. Moreover, selfish decisions are likely to have negative consequences on the collective, as it was pointed out by the seminal essay "The Tragedy of the Commons[3]". It can be argued that the very roots of urban planning lay on the counteraction of private interests in favour of the public good[4]. Individual preferences must be considered with regards to the consequences derived from their satisfaction and, eventually, subdued to the common welfare and fair redistribution of gains. However, liberal economists would disagree, as they have typically rejected the redistributive nature of planning, which they consider an excessive interference of public authorities that limits free market and, consequently, economic progress. In addition, the imposition of unpopular targets (against individual will) may not be as effective as expected, due to the strong inertia of behavioural patterns. For these reasons, performance criteria is a complex matter that needs to be carefully studied, balanced and considered in relation with each case's specific characteristics.

In the origins of urban history, access to fresh water and food were the most fundamental prerequisites for the survival of any human settlement, either permanent or temporary. If these supplies were cut off, the whole community would expire in few days. The location of primitive villages was based on access to food and water. The proximity of a river and available land for agriculture and farming were essential elements to satisfy the basic human needs. The fulfilment of these primal needs would allow the evolution towards urban specialization and the consequent rise of arts, culture as demands of a secondary order, as they were not critical for survival. The advent of trade reduced the need for local production and different priorities emerged, such as connectivity or centrality, to encourage commercial interaction. Other requisites responded to cultural factors. For example, the ideal of city for ancient Greeks implied a moderate size, because a large population would entail difficulties in their system of governance. The democratic assembly required broad participation and the debate could not be handled if the number of citizens, entitled to take part, were excessive. Therefore, size was a criterion for goodness in the Greek polis. Likewise, defensive capacity was key for feudal settlements as it was resistance to fire in late seventeenth century London[5]. Other measures of performance could respond to spiritual reasons, particularly in Chinese and Indian ancient towns, where emerging pseudosciences (geomancy, Feng Shui) dictated location, orientation, earthworks or planting to maintain terrestrial order and cosmic harmony[6]. Almost all these values could be argued to be subjective or of relative importance in comparison with requirements which were truly critical to

1 Matthew 7:18 Holy Bible

2 Lynch, 1981 p.47

3 The Tragedy of the Commons is a metaphor on how the consideration of individual satisfaction only can lead to collective decline, thus eventually affecting every individual. Harding, 1968 pp.1243-1248.

4 Busquets, 2006 Simmie,1994

5 In reference to London Great Fire of 1666

6 Lynch,1981 pp.74-79

sustain communities. The progressive complexity of cities, scientific achievements and fluctuating politics would provide diverse backgrounds in which collective priorities of urban societies were constructed thereafter.

3.2. A definition of Sustainability

The current discourse about the performance of cities is overwhelmingly dominated by the sustainable development ideal, which provides an all-encompassing ideological framework to endorse diverse targets and agendas. Its modern notion was originally defined by the Brundtland Commission in the famous report "Our Common Future"[7]:

"Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future (...) Sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development; and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations"[8]

These words have been repeatedly extolled, interpreted and paraphrased by almost every government, institution or scholar over the last twenty five years[9]. The term has been so hackneyed that it has become part of vacuous speeches, a necessary attribute for the marketing of products and a prerequisite for public and private plans and programmes. However, the banality that resulted from its overuse should not be interpreted as a flaw of the original statement. The term accurately describes the plight that has taken up recent generations' concerns and fears: the endless human prosperity that endangers its own welfare. This is just, however, a preliminary notion of what lies behind the concept "sustainable development", a purely anthropocentric philosophy which, as McHarg had ventured, "*believes that the world, if not the universe, consists of a dialogue between men, or between men and an anthropomorphic God*"[10]. If it can be assumed that the ultimate objective is human wellbeing, or "eudaimonia"[11] , the virtue of sustainability is only instrumental, a means to satisfy human needs. This is a legitimate but rather pragmatic aspiration of sustainability as can be read from its original definition. Contrary to some interpretations, it differs from ecologist or environmentalists in the sense that nature is not valuable in itself but, as McHarg foresaw forty years ago: "*Nature is then an irrelevant backdrop to the human play called Progress, or Profit. If nature is brought to the forefront, it is only to be conquered-man versus nature*"[12]. Sustainable development has, therefore, acquired a broader and more general meaning than ecological or environmental concepts, which are often mixed and confusedly interchanged.

3.3 Sustainability as third environmental revolution

The chronicle of the collective preoccupations that preceded the formulation of the universal definition will show the shifting priorities of modern civilizations and it will help to understand the processes that gave rise to the sustainable agenda. The connection with urban disciplines is revealed by the analysis of the emergence and evolution of town planning, which alternates periods with a strong environmental focus with phases of different priorities. A sequence is repeated over and over in a continuous loop. Each cycle is triggered by events that raise social awareness about the existence of an environmental or social problem. This is followed by a consensus and a collective demand for action to mitigate the impact caused by the initial events. Finally, new regulations are enacted to increase control upon potentially harmful activities, thus collective concern can move on to other issues. In this chronicle, two cycles can be identified since the second half of the 19th century, each one composed by three phases: emergence, consolidation and abeyance. Following this sequence, the current sustainable agenda represents a third cycle or environmental revolution[13], triggered by a resurgence of environmental concerns. This division is a synthetic simplification of facts which are, in fact, mixed and overlapped. Each of these phases has contributed, with theory and experience, to reach the current degree of complexity and heterogeneity in the alternative formulations and instruments that complement urban disciplines today.

3.3.1. The first cycle: social consciousness as origin of modern urbanism

Origin

Notwithstanding earlier precedents of modern town planning[14], the turning point between the punctual resolution of problems and the need for a global and systematic response arises with the Industrial Revolution, whose epicentre was located in England, but it also affected living conditions of workers in Germany, France and Italy[15]. The advent of industrial production pulled in a demographic

7 WCED,1987

8 Ibid.

9 Just as example, British Government definition of Sustainable Communities as "Places where people want to live and work, now and in the future" at HM Government, 2005

10 McHarg, 1969 p.44

11 Eudaimonism,in ethics, a self-realization theory that makes happiness or personal well-being the chief good for man. The Greek word eudaimonia means literally "the state of having a good indwelling spirit, a good genius" (Encyclopedia Britannica)

12 McHarg, 1969 p.44

13 Revolution is used here for its convenient ambiguity: as far reaching changes and as single complete axial turn

14 The concern for the excessive growth and densification of the city already existed in the 16th century in cities such as London (Rasmussen, 1937, pp 63-75) or Paris (Sabaté, 1999, pp 33-37), which gave birth to the first laws and urban regulations

15 Spanish industrial cities, such as Barcelona or Bilbao had a late industrialization

Fig.3-2 Over London by Rail, engraving by Gustave Doré (reproduced from Cunningham, G. & S. Barber,2007)

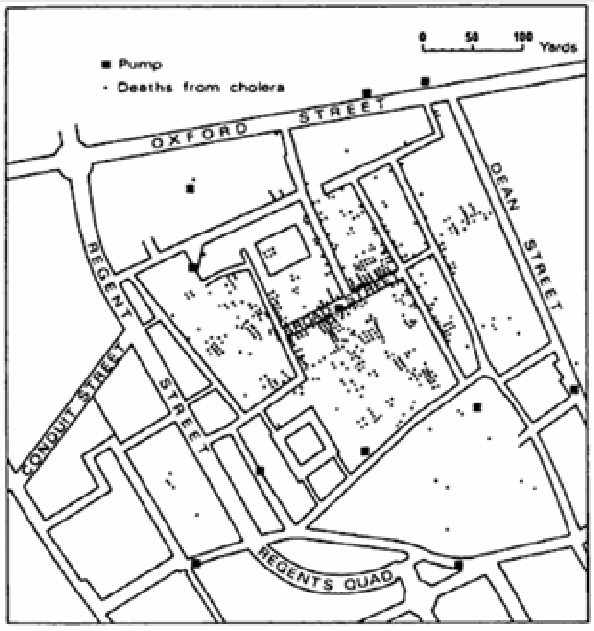

Fig.3-3 Deaths from cholera in the Soho district of London (reproduced from Hall and Tewdwr-Jones, 1978)

explosion in cities that had to be absorbed, either by uncontrolled overcrowding in the existent fabric, or by the creation of slums[16], areas where the working class subsisted under extremely unhealthy conditions. From today's perspective, the effect that the Industrial Revolution had upon the natural environment was, actually, less damaging than the impact upon the working classes. However, both aspects were closely related since the same emissions that destroyed the vegetation and contaminated the rivers were producing dreadful epidemics in the slums[17]. Initially, this was considered acceptable, partly due to the fatalism of the poor classes and, partly, due to the assumption, from the elites, that it was the price for progress: "where is dirt, is money."[18] However, the high classes would soon realize that they were not immune to diseases like cholera. In addition, the appalling conditions of the slums were crudely related by Friedrich Engels in "The Living Conditions of the Working Class in England"[19]. Consequently, reformist groups emerged to demand solutions for the most deprived sectors of the industrial British society. The reaction was not immediate though, for there were three main obstacles: first, the Parliament's initial indifference, secondly, the inability of the administrative structure to exercise a real control at local level and, thirdly, the lack of technical knowledge[20]. In 1832 industrial cities secured representative positions at the British Parliament for the first time, which favoured a more decided reformist interest. Regarding the administrative structure, a series of laws, between 1835 and 1875, paved the ground for a deep restructuration of the districts and counties of the country that would help to clarify responsibilities about sanitary control (under supervision of a central organism) and to endow local entities with planning powers (demolition of unhealthy buildings, plans for slum improvements and models of ordinances and by-laws)[21]. As for the technical knowledge, the correction of insalubrious conditions generated a demand for specialized environmental research that would result in important technological advances.

Early environmental research focused on the identification and mitigation of the epidemics' causing agents. Edwin Chadwick[22] discovered the connection between the propagation of endemic diseases in the working class with the presence of waste, excessive humidity and filth in streets and water courses. Chadwick proposed solutions like the improvement of ventilation in dwellings and the implementation of sewage systems to eliminate the waste from the streets[23]. Soon after, Doctor John Snow identified

16 Slums arouse as spontaneous neighbourhoods of tiny and usually terraced houses that left small voids for access or patios. They were located in the margins of water channel to which they poured the waste and they were typical of industrial cities such as Manchester or Glasgow. In London the slums arouse from the overcrowding of existing neighbourhoods.

17 "The chlorine liberated in the atmosphere of the city of Widnes not only destroyed the vegetation of the moors, but rather it also attacked gravely the denture of its inhabitants" (Tandy, 1975, p.35)

Life expectancy was 41 years in England 1841, but in highly industrialized cities such as Liverpool or Manchester it decreased to 26 and 28 years respectively (Hall & Tewdwr-Jones, 1978 p.15)

18 Tandy ,1975. p.28

19 Engels, 1844

20 Hall & Tewdwr-Jones,1978 p.15

21 Ibid.

22 Edwin Chadwick had evolved in 1838 the Act of the Poor and would participate in the reform of local administration that endowed municipalities with sanitary control (González-Cebrián, 2010 p.142)

23 Chadwick, 1842 p. 369

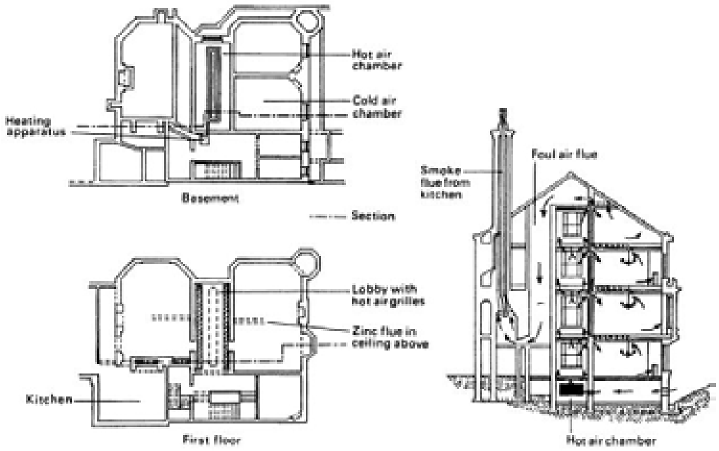

Fig.3-4 Technology provided solutions for deficient internal environments. The Octagon, Grove st. Liverpool by Dr John Hayward for own use1867 (Banham,1969)

Fig.3-5 The first modern air-conditioning system, installed in the summer of 1902 at the Sackett & Wilhelms printing plant in New York (Schultz, 2012.)

a well of polluted water as the origin of a cholera outburst in London Soho, which emphasized the importance of the control of water for human consumption[24]. Doctor Snow used, for its analysis, a map of the area that he superimposed to the location of water pumps and the place of residence of deaths from cholera (fig. 3-3), in what is considered an early precedent of spatial analysis. After the origins of the epidemics had been identified, studies addressed the building's internal environment, aiming to improve the conditions inside houses and workplaces. The death or illness of workers was a burden for productivity. For this reason, research in this field was not so dependent on public or philanthropic initiatives. It was in the companies' interest to ensure a minimum air quality inside their factories. The internal atmospheres had a high concentration of pollution due to the breathing of the workers and the emissions produced by the machinery. A constant supply of fresh air was essential, but the low quality of the external environment limited the potential for natural ventilation. By the mid 19th century technical advances were introduced in domestic environments [25](fig.3-4). At the turn of the century, a young American engineer, Willis Carrier, presented a new system that would transform the relationship of architecture with its surroundings forever (fig.3-5). In his intent to displace the powder from the ambient air of a cigar factory, he invented a mechanism that combined ventilation and refrigeration, thus creating a "manufactured climate" or the first "air conditioning" system.[26]

After the administrative and parliamentary reform and with a committed scientific research, conditions were favourable for the promulgation and implementation of environmental laws. In 1863, an act was passed to limit the atmospheric emissions from industry, the Alkali Act, which was amended and extended in 1906[27]. In 1875 the Public Health Act was promulgated to allow the recently restructured local administrations to formulate building by-laws to control the height, structure and layout of buildings, as well as the width of streets. The instruments of environmental control were further supplemented with the Rivers Pollution Prevention Act in 1876[28]. The effectiveness of these laws was by no means immediate, as it can be deduced from the descriptions of Ebenezer Howard in 1898, when he defended the need for a new city model:

*"but the sunlight is being more and more shut out, while the air is so vitiated that the fine public buildings, like the sparrows, rapidly become covered with soot, and the very statues are in despair" (*Howard, 1898 p. 47)

Howard's garden city was in line with more drastic theories, which advocated for overall solutions, beyond the existent urban fabric. Arturo Soria, Tony Garnier and Howard's proposals rejected the continuity of the current urban system and proposed a different approach, based on new spatial models. They sought not only for the improvement of the environmental conditions, but also for the mitigation of the imbalances introduced by the industrial productive system. Despite the experience of the lineal city of Madrid and its recurrent evocation, the model that would reach a quicker and greater significance was Howard's Garden City. His treaty of principles "To-morrow: A Peaceful Path to Real Reform" was

24 Hall & Tewdwr-Jones, 1978 p.16

25 For instance, the system of central heating that Dr. John Hayward designs for its own house in Liverpool in 1867 (Banham, 1969, p. 36)

26 Ibid. p.30

27 Factories that used alkalis generated harmful emissions that damaged vegetation. This law forced factories to control or to cease these emissions

28 Wood, 1999 p.252

depicted as "the most important work in modern planning "[29] and it meant the beginning of a movement that would extend to the continent and United States. The initial experiences in Letchworth and Hampstead are still recognizable today, although they have been swallowed up by London's growth. The spatial and typological concepts of the garden city have been systematically revisited during the 20th century.

Consolidation

The garden city theory was the last theoretical contribution to the elaboration of the first Town and Country Planning Act[30], which tried to agglutinate different experiences in order to achieve "healthier homes, more beautiful houses, a dignified city and pleasant and healthy suburbs"[31]. The law focused on questions of public health and buildings and it consolidated the empowerment of local entities for environmental control. It also provided new instruments to delineate residential areas, although its main flaw was the inability to forbid urban development in unsuitable locations. Therefore, planning principles were being gradually introduced, accompanying environmental concepts that had been advanced by previous sectorial norms and experiences. Reformists' groups were slowing the pressure as some positive results were being realized. In 1909, Raymond Unwin reported on the positive effects that the previous norms had already had on English cities:

"(...)much good work has already been done. In the ample supply of good water, in the drainage and removal of waste matter, in the paving, lighting, and cleansing of streets, and in many other such ways, probably our towns are served as well as, or even netter than, those elsewhere. Moreover, by means of our much abused building by-laws, the worst excesses of overcrowding have been restrained." (Unwin,1909 p.3)

Abeyance

The decrease in the reformist pressure marked the beginning of a period characterised by the consolidation of building ordinances and minor changes in environmental legislation (upgrade of the Law of Public Health in 1936 and the consolidation of the Town and Country Planning Act in 1925 and 1932) that would extend until the end of the Second World War (WWII). Urbanization became more intense in the post-war, a time characterised by reconstruction and housing shortage. British, and also American cities, engaged a different urbanization model respect to continental Europe. This diversion would define the diverging sensibilities of environmental disciplines that can be still traced today. The hygienist reforms undertaken in United Kingdom had extended to other countries such as Germany, Spain or Italy, which had suffered similar problems, although not so intensely[32]. However, English cities expanded towards the periphery, where labour classes could find affordable houses in low density residential suburbs, connected to the working centres by means of effective railway lines. In contrast, European capitals were growing in a rather compact way, keeping high densities and collective housing blocks as main typology (figs.3-6 and 3-8). Moreover, early planning regulations that had been passed in England provided powers to control the form of new buildings but not to prevent a landowner from developing a greenfield site. It had a doubly negative consequence: on the one hand, great amount of agricultural land was being urbanized, with the

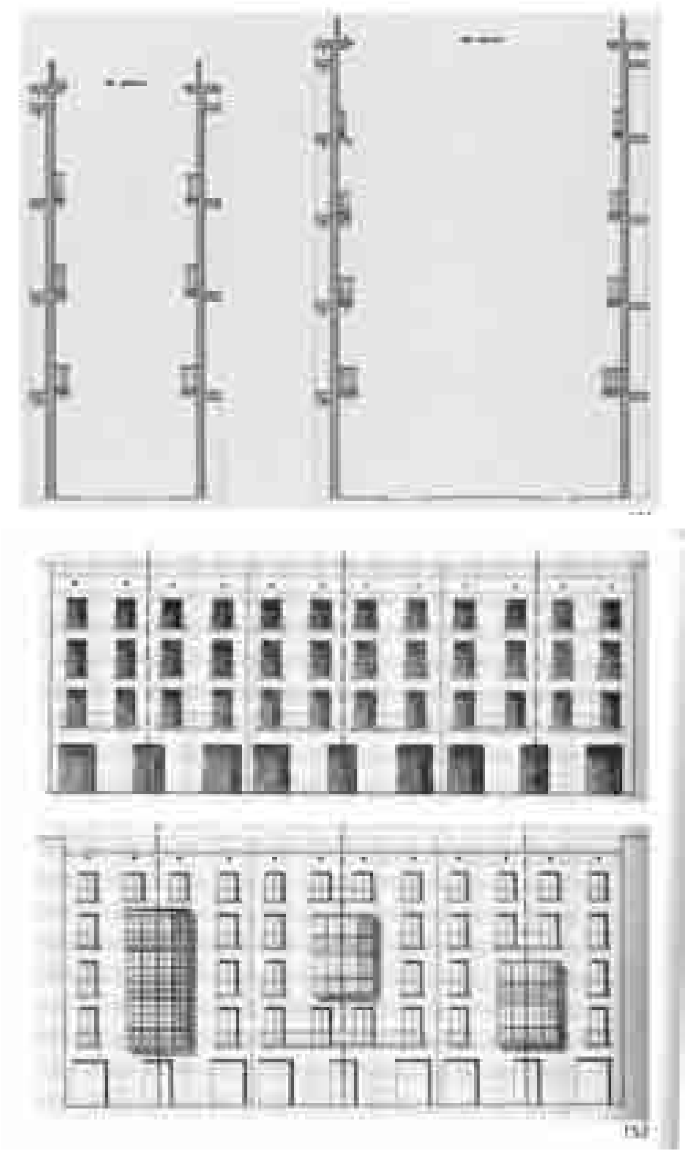

Fig.3-6 1856 Barcelona's Ordinance profiles, setting building height and street width and composition scheme (Sabaté, 1999)

29 Hall, 2003
30 Housing, Town Planning, Etc. Act 1909
31 Cullingworth & Nadin, 2006 p. 16

32 Ladd, 1990 p.37

Fig.3-7 Urban sprawl and erosion of farmland in UK. Hendon Central Station 1923-1926 (aerofilms ltd., britainfromabove.org.uk)

Fig.3-8 Karl Marx-Hof in Vienna (1926-1930) The collective housing has traditionally been more popular in Europe than in UK, where even slums were low rise (reproduced from AV Monographs,1995)

consequent loss of local food production and, on the other hand, the distance between residence and work increased, since industries were not decentralizing at the same pace as residents. The Town and Country Planning Act of 1947 introduced a critical innovation to control the continuous erosion of the countryside, the power to regulate the location and extension of new urban areas[33].A similar pattern, based on urban sprawl, would be also adopted in the United States, with the main difference that private cars prevailed over public transport. Apart from this, urban planning entered a pragmatic period where juridical and administrative elements were incorporated, seeking for the effective management of reconstruction and recovery. Consequently, environmental considerations were sidelined and limited to ad hoc resolution of sporadic problems. Nevertheless, it was not a complete stop in research since other emergent disciplines would keep up with work that would come out in the next paradigm shift.

3.3.2 Second cycle: ecological awareness

Origin

The ninety sixties brought the consolidation of the welfare state. The new political situation reinforced the prevailing position of the United States, which led many European academics and professionals to move there, attracted by the openness and stability of the country. The American notion of Environmental Planning was closely related to the tradition of Landscape Architecture, whose great pioneer Frederick Law Olmstead, had learnt the work of the British reformists and merged hygienist engineering with the topic of the park in his

33 The Town and Country Planning Act 1947 lies the foundations of current planning system in United Kingdom

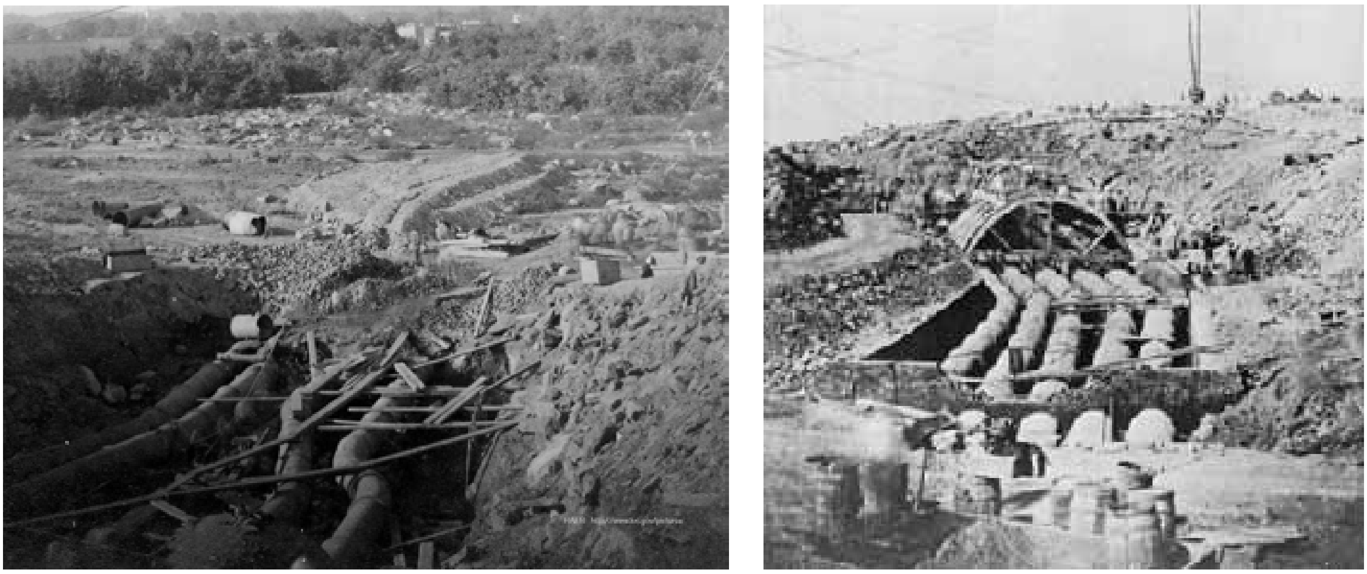

Fig.3-9 Central Park drainage system (Source: Library of Congress USA)

first masterpiece: Central Park. The Park is a vast green mass that structures the isle of Manhattan, not only above ground but also in the underground, since the main infrastructures of the island circulate underneath the green area (fig. 3-9)**.** It symbolizes the American contribution to modern planning, with natural landscape understood not only as a purifying agent but also as a necessary element to articulate the built environment. This approach was developed by the Regional Planning Association of America (RPAA), led by his most notorious member: Lewis Mumford. They defended the need for regional planning of organic character in such a way that *"every place and every natural resource, from forest to city, from mountain to sea level, can be developed in balanced harmony, so that population is distributed in such a way that they have access to those resources and their natural advantages, instead of neglecting or spoiling them*"[34] These ideas did not receive enough support though, as the RPAA stayed in a position of certain marginality and their real influence was limited to the academic world and critical circles.

The professional world was, however, more concerned with the reconstruction and solving the housing shortage. Academic institutions assumed the role as research centres to integrate scientific methods in the fields of architecture and urbanism. Victor Olgyay at Princeton, Ian McHarg at the Landscape Architecture Department of Pennsylvania or Eugene Odum at the School of Ecology in Georgia worked on new methods and theories that set the ground for the subsequent development of new disciplines[35]. In Europe, the Architectural Association, under direction of Maxwell Fry, launched a pioneering diploma in Tropical Architecture, which was one important precedent regarding the integration of bioclimatic studies in the architectural academic curricula.

Consolidation

During the ninety sixties, a series of accidents, of industrial origin, caused severe damages in natural areas of the United States. The great repercussion that was given to those disasters by the mass media was coincidental with two cult publications: The Silent Spring by Rachel Carson, which denounced the noxious effects of certain industries upon the environment and the previously mentioned Tragedy of the Commons, by Garret Hardin, who approached the topic of resource depletion. The concurrence of these events sensitized public opinion and awakened a collective ecological awareness that would provoke a new wave of social pressure, similar to the reformist movement of the 19th century. The response to this pressure was a renewed interest in instruments that, even if they could not solve the problem, they could, at least, transmit the idea that industries and governments were taking the environment into consideration. Research that was started in previous years would find applications in this breeding ground, which also produced a key environmental law: the National Environmental Protection Act (NEPA) enacted by

34 Lewis Mumford quoted by Sica, 1981 p.675

35 Design with Climate (1963) by Victor Olgyay is one of the reference textbooks of bioclimatic architecture in the 20th century; Ian McHarg formulated in Design with Nature (1969) a method of environmental planning in which he studied the suitability of the territory for certain activities and he advanced geospatial analysis; Eugene Odum broadened the field of ecology by his definition of ecosystem in Fundamentals of Ecology (1956), years later he also categorized the city as an open ecosystem (Bettini, 1996, p. 77)

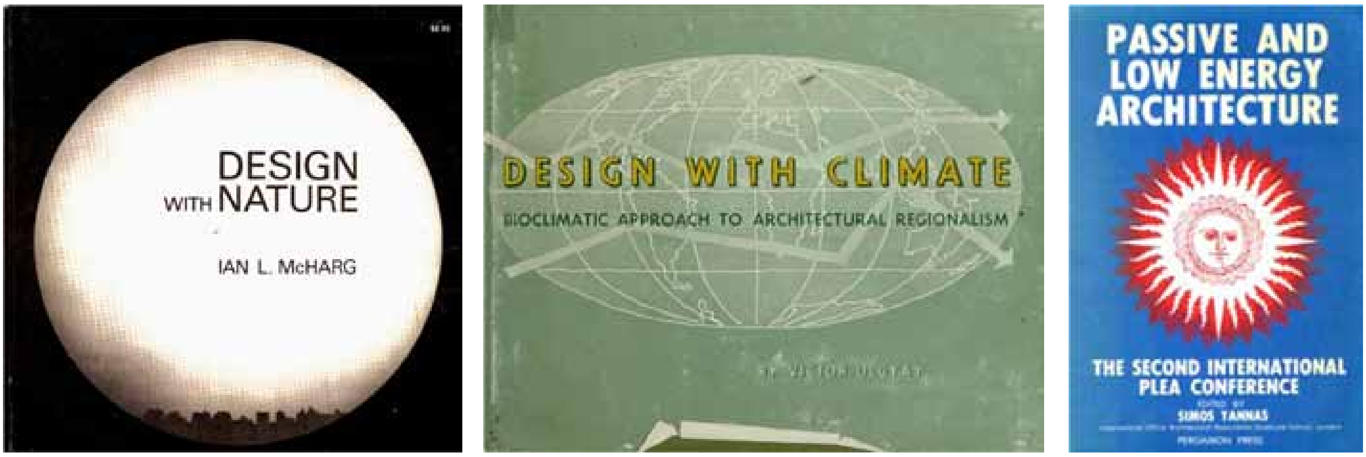

Fig.3-10 Some key publications from the sixties and seventies had a strong emphasis in the relation man-natural environment (McHarg, Olgyay). In the eighties energy becomes an essential part of the agenda (cover of Plea Proceedings, Yannas 1983)

the American government in 1969. This law regulated the evaluation of the potentially damaging effects during decision making process when a project was likely to have a negative impact upon the environment. It stipulated the elaboration of a document that must contain data and analysis about the possible consequences from public plans and policies, called Environmental Impact Statement. Despite certain methodological deficiencies, it created a demand of predictive and assessment tools in fields such as atmospheric pollution, biodiversity or water quality. The European equivalent would take more than fifteen years to be agreed[36]. It was partially inspired by the American and each member state had to adapt it to their respective countries.

The consolidation of the natural environment and its preservation as a high-priority meant a shift in scale and scope respect to the previous cycle. The hygienist-engineering view, concerned with the health of city workers, is now supplemented with a broader perspective, which pays more attention to the territory, and revisits regionalist theories from Geddes to McHarg. However, new problems would soon arise, that would trigger a demand for different considerations: the energy crisis. The oil crisis of the seventies, although brief, exposed the high dependence on energy sources whose supply was limited and highly unpredictable. The need to control the high voracity of the welfare society was realized at all levels. In this scenario, investigations in thermodynamics and bioclimatic alternatives outlined by Olgyay, Koenigsbeger, Trombe or Balcomb would become more relevant as they offered means to reduce energy demand from buildings by means of good design. Governmental measures pointed to energy issues: in United States, the Department of Energy (DoE) undertook important research and dissemination efforts[37]. In Spain, as in other parts of Europe, basic norms on the thermal conditions in buildings (NBE CT 79) established limitations in the heat losses of constructive elements, such as walls, roofs or windows. On the other hand, it is significant that around that time the School of Tropical Studies of Architectural Association acquired its current denomination as Department of Energy and Environment, combining both notions in a conceptual association that would be kept thereafter. Environmental awareness and energy were the main contributions from the second cycle, which were added to the social approach from the previous one.

Abeyance

As in previous cycles, the environmental momentum was followed by a slow digestion, in which some concepts were consolidated while other ideas fell into abeyance. The political stability in occidental countries favoured the advance of the capitalist model, based on competition and free market. The decomposition of the Soviet Union and the fall of Berlin's wall meant the end of an era and the consolidation of worldwide globalization. Frontiers were blurred and new markets open for companies to trade their products, and to reduce their labour costs. This was a new burden for western industrial cities, which had started a period of sharp decline since the ninety sixties, which was aggravated with the new possibilities for companies to offshore manufacturing activities. Cities tried to reinvent themselves by becoming service centres (banking, offices, trade, tourism...), some of them succeeded after some struggle (London, New York) whereas others, which were more specialized on single sectors (Glasgow, Detroit), suffered more difficulties and entered into a deep crisis.

36 Directive 85/377 on the assessment of the effects of certain public and private projects on the environment

37 For instance thermo dynamic building simulation software

3.3.3 Third cycle: from globalization to sustainability

Origins

Paradoxically, deindustrialization was accompanied by the increase of urbanization, resulting in the erosion of rural areas. The value of agricultural land could not compete with real estate expectations or overseas products. Worldwide, more than half of the total population passed to live in urban areas, whereas at the beginning of the 20th century only ten percent of the population was urban[38]. This increase was primarily due to the incorporation from the so called "developing" countries (Mexico, Brazil or Southeast of Asia) to the urbanizing process, since the most advanced cities had started shrinking years ago. Indeed, European cities were not growing in population but only in extension. The decentralisation process had been fuelled by improvements in private transport and cheap fuel. The result was twofold, on the one hand it induced a further suburban expansion, and on the other end, the resources to sustain the expanded metropolis (goods, food, waste...) became more intense and globalized , a larger proportion of resources was necessary to satisfy the demand of the population.

The capacity to quantify resources and consumption would acquire a great transcendence in the turn towards sustainability. Early studies of city-wide material accounting were carried out in the late seventies. A study on Hong Kong's energy demand was published in 1978[39], followed by similar studies in Barcelona[40], Madrid[41] and Paris[42], in which the inputs and outputs of raw materials, energy, water and waste were also estimated. These metabolic studies unveiled the high consumption rates in all these cities, which brought to the forefront the argument of Hardin's "Tragedy of the Commons" about the depletion of collective resources. Quantitative studies of resource consumption were abandoned for a while due to the high complexity and relative uncertainty. It was resumed in the mid nineties, using a new method that consisted on the translation of the different measure units to the equivalent quantity of land that would be necessary to generate a resource in hectares: the Ecological Footprint. The Ecological Footprint of any city, country or activity could be estimated and compared with the administrative area that the city actually occupied in the territory[43]. This was an intuitive method that allowed the easy visualization of city's voracity. Most of the studies showed a consumption pace beyond the actual carrying capacity of the territories, and even when the estimates were undertaken at world level, results were negative, this is, the global demand was higher than the available world supply.

38 Rogers ,1997
39 Newcombe et al, 1978 pp 3-15
40 Parés et al, 1985
41 Naredo Trias, 1995
42 Salvador Palomo, 2003
43 Wackernagel & Rees , 1996

It is in this context of resource awareness, two events could be pinpointed as landmarks in the shaping of a new agenda: The first one, was the already mentioned report "Our Common Future" elaborated in 1987 by the Brundtland Commission, in which the concept of Sustainable Development was first defined. One year after that, the World Meteorology Organization (WMO) and the United Nations Environment Program (UNEP) created the Intergovernmental Panel on Climate Change (IPCC), composed by hundreds of scientists from all over the world to elaborate periodic reports for the prediction and monitoring of potential climatic scenarios. These reports confirmed the damaging effects of greenhouse gasses, and their repercussion in global warming. Their findings influenced the adoption of international agreements, such as the Kyoto Protocol, and the widespread application of CO2 emissions derived from each activity or project as a measure of sustainability. New instruments and databases became available to elaborate integral studies on traffic, construction, industry, infrastructure and embodied energy of materials. The impact from every activity could be translated to the tons of CO2 emissions they would generate. Climate change monitoring became one of the most direct indicators of the planet's global sustainability. Consequently, the measures to prevent the former will serve to reach the latter.

Consolidation

Sustainability was already part of the scientific agenda, it had been also introduced in professional sectors such as architecture or urbanism through research niches at the University or by the activity of *conscious* professionals. However, the general consolidation of sustainability as a collective demand was boosted in the year 2007 by the unprecedented worldwide repercussion of the documentary presented by Al Gore about climate change[44]. The film was awarded with an Oscar and the former US vice-president received the Nobel Peace Prize for his diffusion and defence of environmental values (fig.3-11). From that moment, sustainability adopted a new meaning, from being an objective to become a value itself, a label, with advantages (stronger implication, projection and potential for action) and some downsides (information overflow, lack of filters, opportunism and self-promotion).

44 Guggenheim, 2006

Fig.3-11 The important awards granted to former US vice-president Al Gore and the ICCP for the documentary "An Inconvenient Truth" symbolized a renewed interest in environmental topics by the general public (latimesblogs.latimes.com)

3.3.4 The present moment: another phase of abeyance?

The adaptation of architecture and urbanism towards "a more sustainable approach" was received in different ways. The concept has experienced a certain fatigue due to overuse that has resulted in different attitudes from practitioners, these attitudes range from negation to the absolute adhesion. Landscape architect Elizabeth K. Meyer caricatured the different positions regarding sustainability in four categories[45]:

- *"Yawn. They are not against it but they have reservations, they assume that sustainable design is what they have been already doing and they are suspicious of the term used as a form of marketing and opportunist self-promotion*
- *Hug. They see sustainability as a technological challenge, based on the knowledge on the last techniques and systems. They adopt it without reservations even to the cost of a loss in the control of projects*
- *Rejection. They argue that sustainability does not leave breath for design. They rebel against it since they consider it is as a constrain for creativity, and that the products that it generates are poor in form and aesthetics.*
- *Distance. Sustainability is not to discuss and it is not only about its technological merits. They adopt environmental approaches as part of their philosophy but without public militancy."*

These diverse feelings may be partly justified by the increasing perception of sustainability as a ragbag of ideas, some of which are doubtful, unsubstantiated or indecipherable. Certainly, theories, visions and knowledge on the proper arrangement of human activities in relation to the environment have generated a vast amount of information over the last century, indeed the present stage could be characterised as an undergoing "coalescence"[46] of those theories. Current research has covered such diverse disciplines as urban technology and infrastructure, microclimate, building's thermodynamics, life cycle analysis, mobility, social equity, etc... Technological advancements have impelled a strong acceleration both in the analytical methods and in the knowledge dissemination capacity. However, the wide range of factors and the complexity of the analytic tools may hinder the implementation of principles in common practice. The effort that is required to grasp fast evolving concepts, which have not yet been fully incorporated in Architectural Curricula[47], discourages professional's immersion, which might result in defensive attitudes such as those aforementioned. Moreover, the reluctance of market driven agents (developers, design teams, constructors...) to dedicate resources to time-consuming tasks may prevent the general adoption of environmental analysis to inform decision making, which limits the demand for specialized knowledge in a sort of vicious circle. Therefore, the applicability of environmental concepts in planning requires a balance between rigour, simplification and systematization to achieve solid concepts that can be translated in legible instruments for design teams and other stakeholders. The synthesis should not be interpreted as a banal or universal recipe book to be applied by teams as robots. Rather on the contrary, it should

45 Meyer, 2008

46 Forman, 1996 p.29

47 Altomonte, 2010

allow the channelization of common objectives to improve communication within multidisciplinary teams. Architects can contribute with their experience in the coordination of complex projects, their creative response capacity, aesthetic sensibility applied to landscape, built heritage and urban environment, and their greatest knowledge on one of the most important (but not the only one) elements in the formation of the city: its buildings.

The current economic crisis has stopped urbanization in most European countries and has turned social attention to issues such as employment or political corruption. If society had reached a seminal environmental conscious in the last decades, which is doubtful, it is likely that environmental aspects will be again sidelined in the short term if they collide with economic interests. However, the concepts implied by sustainability are no longer matters of choice but necessary attributes for the survival of cities.

3.4. Achieving Sustainable Cities

3.4.1 Concentration versus dispersion

Most of the world population live in cities[48]. As a consequence of the progressive urbanization, traditionally rural societies have engaged urban lifestyles, with all their advantages but at the cost of increasing the pressure upon the environment. Urban immigration is a result of rural families that search for a better life. This phenomenon creates bipolar cities, with wealthy and deprived areas, with poorer newcomers settling in slums to find their way out of misery[49]. Evidence has shown that cities do actually provide opportunities[50] and the success of early migrants will further intensify the demographic flow. Farming and rural communities left by migrants, though poor, were potentially more self-sufficient than cities, as they could produce their own food and satisfy their basic needs with few external resources. In

Fig.3-12 Some concepts involved in Sustainable City definition according to experts. The size indicates the frequency of that word within the arguments to answer the question "What are the qualities that should characterize a sustainable city?" from 20 renowned experts (see Appendix for sources and detailed justification)

48 Marr & Whener , 2012
49 Glaeser, 2011 p.70
50 Ibid.

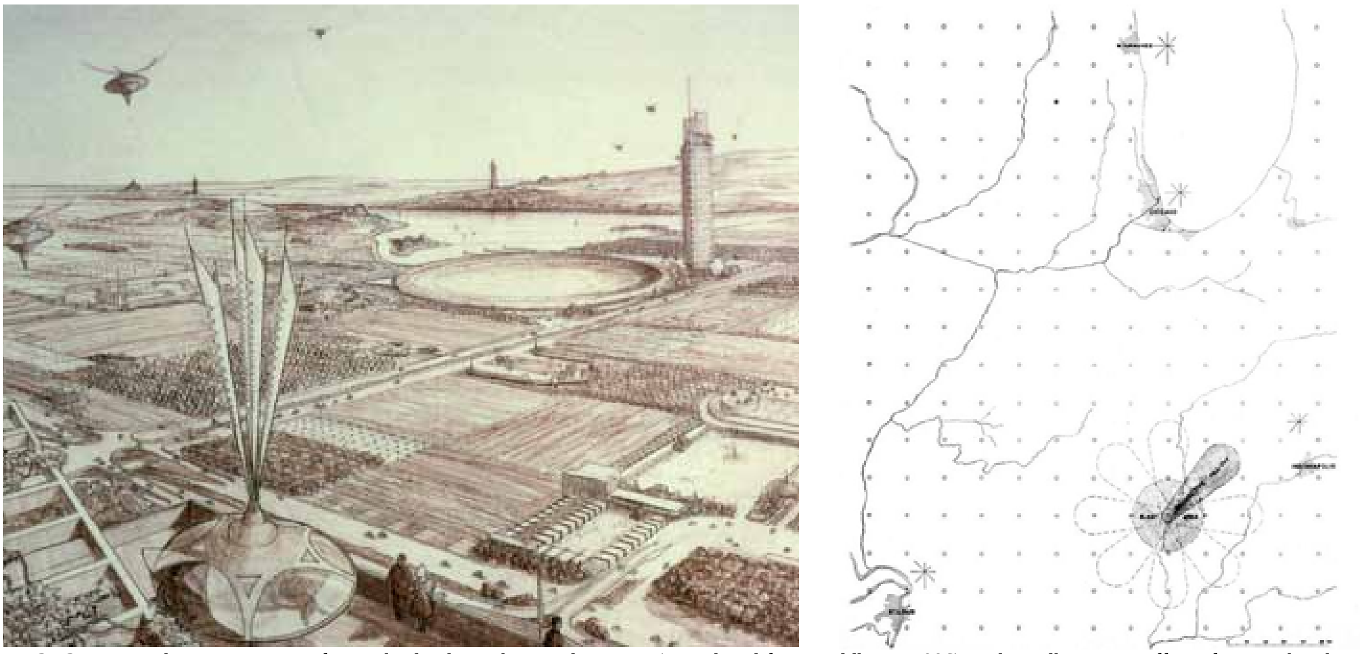

Fig.3-13 Decentralists views: Left: Frank Lloyd Wright Broadacre city (reproduced from Waldheim, 2006) Right: Hilberseimer effect of atomic bomb on decentralized settlements (Hilberseimer, 1955)

Fig.3-14 Densifiers' views Left: Pruitt Igloe Project 1956 (photograph: Bettmann/Corbis) Right: Greenwich village street life, an inspiration for Jane Jacobs (photograph: Doug Keer)

contrast, cities tend to be net degraders of the environment, they need a constant and intense supply of energy, water and goods that are usually imported from elsewhere. One of the consequences of urban concentration is that more people are demanding an additional supply, thus increasing the externalities of cities. Given the scale that this process has acquired, it became evident that any strategy regarding the Sustainable Development ideal should have the improvement of cities as one its main priorities.

If urban concentration is such a burden then, decentralization policies seems an evident solution. This strategy had been postulated by reformists who tried to remedy the effects of industrial cities on their inhabitants. Geddes, Howard, Wright or Mumford envisioned alternative ways to inhabit the territory beyond the boundaries of polluted and congested cities. Even the fear for an atomic cataclysm during the Cold War was used by Hilberseimer to justify the defensive advantages of small settlements, regularly distributed over the territory, against large concentrations of people, who were an easier and more vulnerable target[51]. Countercurrent movements emerged, led by such antagonistic characters as those of Le Corbusier and Jane Jacobs. Both defended density as a positive attribute for urban life. However, while Le Corbusier based his arguments on functional grounds and densification should come by a combination of tower-blocks and vast open spaces[52], Jacobs presented a more social approach with her vision of people interacting in streets, propitiated a by mixture of activities, old buildings and small blocks [53]. Le Corbusier and followers' urban ideal was symbolically declared obsolete in 1972 when, the Pruitt-Igoe development was demolished in Chicago[54], after only seventeen years of use and numerous social and operational problems. Jacobs' legacy would not have the same initial reflection in the city, apart from her successful campaign to save her neighbourhood in Greenwich Village, NY against Robert Moses' (New York master builder) aggressive urban renewal policies. Nevertheless, her militant response was followed by a book that would acquire a great influence in following decades, and to which the advocates of compaction would constantly refer to[55]. In the ninety nineties, urban concentration was definitely adopted as the dominant model for sustainable cities, as it was the only one that could possibly enhance the three spikes of sustainable development: social, economic and environmental.

3.4.2 Sustainable city = compact city

The case for the compact city as a sustainable urban form has been built from a combination of conventions and targets, collectively agreed by intergovernmental panels, based on hypothesis and analysis formulated by technocrats and academics. Three landmarks have had a decisive influence in the foundation of a compact city theory as a sustainable urban form:

- The Brundtland Report, published in 1987. Sustainable Development was defined.
- The Earth Summit at Rio de Janeiro in 1992. Established the need for action at local scale and the implementation of indicators to monitor sustainable development (Agenda 21)
- The Green Paper on the Urban Environment (CEC) in 1990. It explicitly recommended strategies which emphasized mixed use and denser development that, they argued, was more likely to result in "people living close to work places and the services they require for everyday life. The car can then become an option rather than a necessity"[56]

51 Hilberseimer, 1955 p.283
52 Hall, 1988 p.207
53 Jacobs, 1961
54 Jencks, 1984
55 Jacobs, 1961
56 CEC, 1990 p.40

European politicians were especially enthusiastic about the apology of the "European city concept"[57] and they would take any opportunity to include references to urban containment in any subsequent declaration on the matter (Leipzig Charter[58], Toledo Declaration...), the European Union's reference framework for sustainable cities[59] is an explicit praise of the compact city model.

The advocates of the compact city needed evidences to proof their claims, and these would be provided by Australian academics Peter Newman and Jeffrey Kenworthy[60]. They surveyed transport patterns in cities all over the world and related fuel consumption to density. The result showed a close correlation between density and fuel usage that has been used to demonstrate the beneficial effects of compaction for reducing transport energy.

The sustainable tide was overwhelmingly in favour of the "centralist" side, supporting the densification of cities to enhance vibrant, dynamic and mixed urban life. The apparent gloominess of contemporary suburbs and the remembrance of Corbusian planning failures were to be overcome by the appeal to the charms of medieval towns. The romantic townscapes of Italian villages or Jacobs' beloved West End were depicted as examples of dense urban quality. On purely environmental grounds, and after Newman and Kenworthy's report, it was relatively easier to find objective arguments to support the case. Two claims were repeatedly alleged in the defence of urban compaction:

- In compact cities the need for travel is lower and public transport results more efficient. Consequently, transport energy and emissions can be potentially reduced.
- Urban densification prevents the transformation of Greenfield land and reduces the loss of valuable habitats.

Although any of the claims has remained undisputed, evidences seem to suggest that those arguments were consistent. Other claims may still need further research to present clearer evidences since, to date, no absolute conclusions can be extracted on hypothesis that remain being debated, such as:

- Energy demand from buildings is lower in compact cities[61]
- Energy efficient systems are only viable in high dense areas (e.g. Combined Heat and Power)[62]
- The concentration and mixture of activities improves life quality and enhances economic prosperity[63]

57 European Union, 2010 p.7
58 European Union, 2007 p.4
59 www.rfsustainablecities.eu
60 Newman & Kenworthy, 1989
61 LSE & EIFEL 2010
62 Owens, 1987
63 BCN Ecología Urbana , 2007

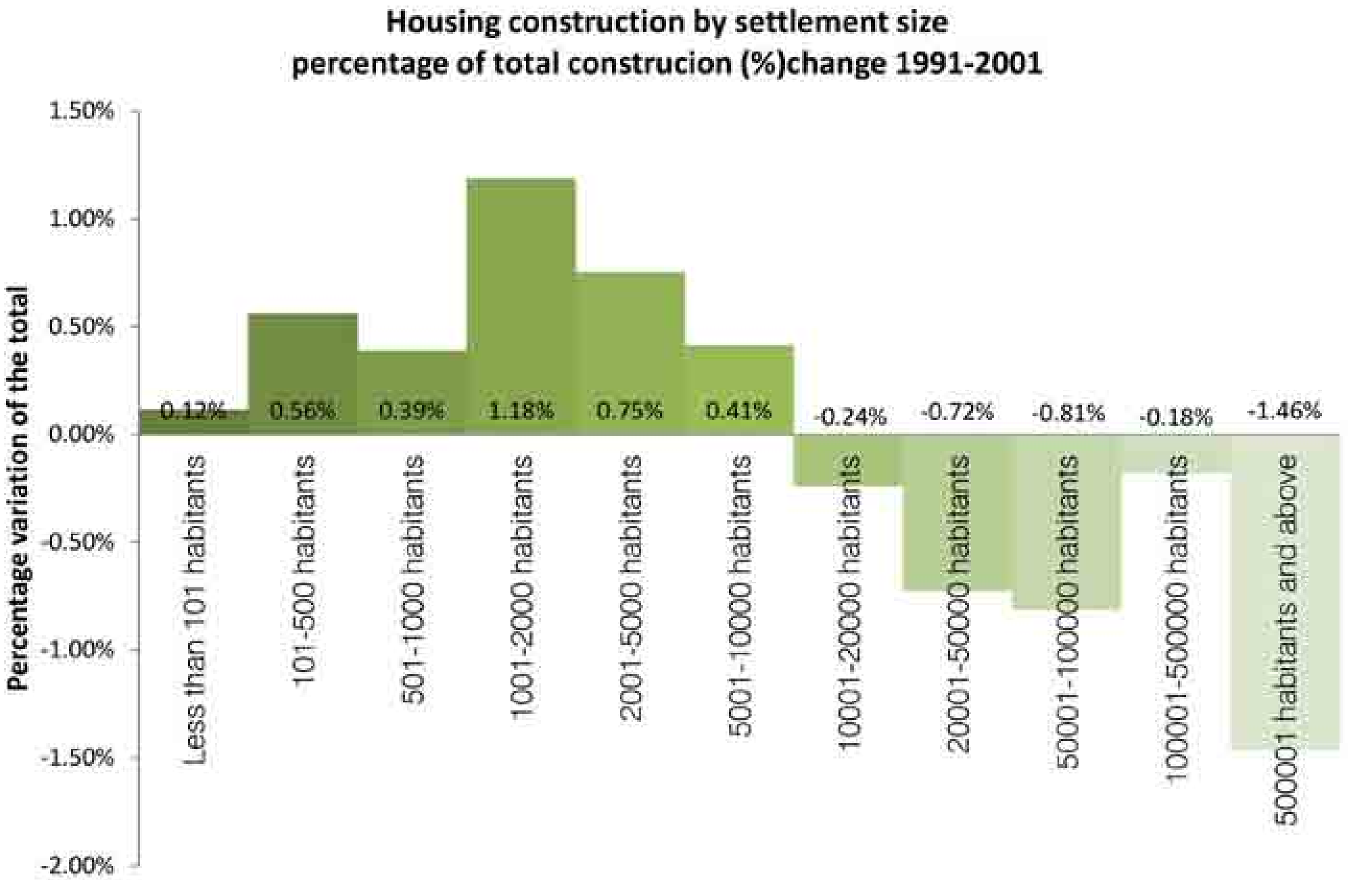

Fig.3-15 Decentralization of housing construction in Spain between 1991 and 2001 (source: author, with data from National Statistics Institute)

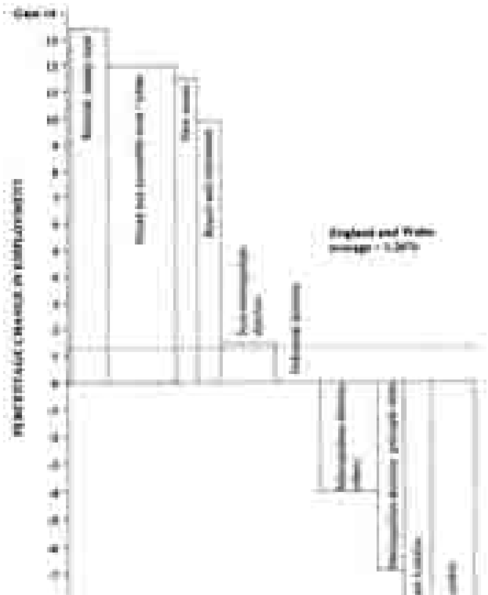

Fig.3-16 Decentralization of employement location in United Kingdom (Breheny, 1995a)

Despite the apparent unanimity and the commitment of European governments[64] to promote the compact city, the reality showed a much more hesitant attitude. In Spain, deregulation of land from 1998 to 2007[65] paved the ground for speculation with Greenfield land and it accelerated decentralization processes. Likewise, the UK Eco-Towns programme, launched in 2007, projected new towns over the English countryside, although under strict sustainable standards[66]. Regardless of how environmentally friendly the resulting settlements could be, many of these Eco-Towns would imply Greenfield transformation and therefore they could barely fit into the compact city concept. In practice, public administrations were funding technocratic reports to exalt the advantages of the European traditional city (e.g. Urban Task Force report[67] in UK, and Green Book of the Urban Environment[68] in Spain) while deregulation and market initiatives were still leading the way towards decentralization (figs. 3-15 and 3-16). The theoretical debate was therefore

64 European Union ,2010
65 Ley 6/1998, de 13 de abril, sobre régimen del suelo y valoraciones (Land Regime and Valuation Act 6/1998)
66 CLG ,2007
67 Urban Task Force ,1999
68 Rueda Palenzuela et al , 2007

Fig.3-17 Top Left: Centralists' view on compaction, Barcelona's Rambla (photograph: C. Lorenzo) Decentralists arguments are illustrated by examples of pollution (bottom: Madrid, photograph:S. Alcántara) and traffic jams (top right: Sao Paulo, photograph:F. Inklaar)

detached from reality, technocrats and academics supported by governments elaborated the golden rules of sustainable cities in a top-down approach. An apparent consensus was being built under the naive assumption that the multiple colliding interests, those which were actually deciding and transforming cities with the complicity of the same governments and local authorities, could be washed away overnight. Many of the proposed solutions underestimated the importance of practicality and feasibility as they failed to involve the essential agents of urban life such as residents, companies or developers.

3.4.3 The downside of urban compactness

If Europe was the model and the epicentre of compact city theories, North America would lead the reaction against urban concentration[69]. One of the earliest obstacles for urban intensification was the phenomenon known as NIMBYism[70] (Not In My BackYard), consisting on pressure groups formed by residents that raise and oppose to changes that they consider negative for their areas. Examples of this kind have occurred in suburban enclaves in New York and London, to react against intensification and town cramming[71] in a similar manner as Jane Jacobs raised to defend Greenwich Village. The negative perception of densification by dwellers is adduced as a main argument by the opposers to urban compaction. They maintain that there is an inevitable loss of urban quality, associated to overcrowding, diminution of open space, gardens and privacy, as well as high levels of noise, traffic congestion and pollution. They argue that even though there may be some benefits, in terms of transport energy or landscape preservation, the gains may be trivial relative to the pains[72]. The idyllic view of urban living represented by centralists was embodied in Barcelona, Amsterdam or the fashionable London neighbourhood of Bloomsbury[73]. All these are vibrant urban centres that project a snobbish perception of density. This vision is now confronted with Calcutta, Cairo or Sao Paulo, to illustrate the other side of urban congestion (fig. 3-17). In summary, the arguments for decentralization defend that certain societies are so fond of rural and suburban living and it has been incorporated so profoundly that it is now assumed an inalienable right by its citizens. It is highly unlikely that drastic changes can be successfully implemented without the complicity of the local community and, therefore the compact city model would be unfeasible in those places with a strong suburban tradition.

69 Breheny, 1995
70 Glaeser, 2010, Burton, Williams & Jenks, 1995
71 Burton, Williams & Jenks, 2000
72 Breheny,1995a
73 Urban Task Force , 1999 p.59

Quality of life was not the only claim that was contented. Even supposedly scientific arguments were vigorously challenged by sceptic researchers. Newman and Kenworthy's survey, the ultimate evidence for centrists, was severely criticized from the US. They were accused of rendering their research with ideology and presenting important technical gaps, as well as misleading conclusions. Breheny[74] cites reports from Gordon and Richardson[75] and Gómez-Ibañez[76] to exemplify some of the views that questioned the Austrialian's findings. The formers, American economists, presented data from their country to show how relocation of workplaces in suburbia was causing commuting distances to stabilize, despite ongoing decentralization. They argued that market pressure would dictate the most efficient urban model, including those aspects of energy. Likewise, Gomez-Ibañez pointed out the disregard of Newman and Kenworthy on the effect that factors other than density, such as household income or fuel prices, have had in the gasoline consumption in surveyed cities. He was also wary on the cost that radical compaction could have on economic and life quality aspects if the debate was monopolized for deep green environmentalists for whom "these losses were acceptable by definition"[77]

3.4.4 The Economy and the compact model

The effect of containment in the urban economy would also rise converging arguments. One of the premises of planning, assumed since the ninety seventies, had been that physical changes in the urban structure would deliver an economic response[78]. In the aftermath of a property crisis one could argue that an inverse situation, where urban transformations have merely responded to the immediate needs of the economy, is rather the case. Some of the most important urban transformations in the last thirty years could be read as manifestations of economic interests. In London Docklands regeneration, the market dictated what was needed at any given moment to maximize profits. It was argued that it was the only realistic option to regenerate the former industrial states in a short period. In contrast, Barcelona's local authorities traced a strategy of public interventions to revitalize its seafront, formerly industrial land, assuming that, once the area was cleaned up and served by good infrastructures, it would become a prime location for high end companies, thus boosting the city's economy. If the short term success of these examples was strictly proportional to the public and private investment, their long term performance remains unclear and it will be a subject for analysis in following chapters.

Fig.3-18 What people want. Iconography of social welfare, advertisement of Golders Green suburb, to the North of London (source: London Transport Museum)

Economic prosperity has been seldom represented by suburban or rural landscapes (fig.3-18). Social welfare imagery may portray the dream house with a garden and a big car peeping from a shed. If the idea is to really depict wealth, then urban scenes, with shiny skyscrapers and elevated railways shall provide such symbolism more properly (fig. 3-19). The city has been associated to economic activities since its origins, the division of labour allowed specialization and trading, which was better done in places with good access and concentration of people. The industrial revolution increased the need for manpower, which should, preferably, live near production centres. The extreme densification was not a problem but a favourable condition in the emerging capitalist system. The "industrial reserve army"[79] would keep

74 Breheny, 1995b
75 Gordon & Richardson, 1989
76 Gomez-Ibanez, 1991
77 Breheny, 1995a
78 Fainstein, 2001 p.98

79 Marx, 1887 p.428

Fig.3-19 What business want. Iconography of economic prosperity, Canary Wharf financial centre in London

wages down. It is not a novelty then for economists to exalt the merits of a dense city model. They typically allude to the enhancement of interaction between skilled people, a point that was already made in Alfred Marshall's "Principles of Economy" at the turn of the 19th century.[80] Contemporary classics such as Manuel Castells or Edward Glaeser also agree on the conception of cities as "milieu of innovation"[81] and they strive to prove the "intellectual advantage of proximity"[82]. The good city form, from the economic perspective, would therefore reduce distances, primarily among working centres and, if possible, between jobs and homes, by means of concentration and densification. These needs may collide with people's preferences, especially in places like London, where flat accommodation is considered as something temporarily and of low quality, and create tensions between communities and development agencies.

The aforementioned approaches have primarily considered the location preferences of large companies to undertake their operations, thus they study land use and urban form in relation with market activities. But land is also a source of wealth in its own right, which is channelled by the real-estate industry, representing a critical element in the urban economy[83]. From this point of view, the preferences of the stakeholders may differ, depending on their property rights on the land. Developers that had already purchased land in a certain area would probably prefer to keep or increase its allowable density so their property is not devaluated while companies seeking for land may prefer to keep expectations down while they are dealing with landlords. Notwithstanding the opportunistic wishes from real estate companies, this is not really meaningful for the study of the city, as it only responds to their particular short term interests. However, when the question is put in more abstract terms, this is, referring to types of development that results more attractive to real estate industry based on market's demands, a sharper insight is then provided. Breheny[84] reports about two different surveys among house-building companies and office developers in UK that found a generalized reluctance against infill Brownfield sites, especially in office sector. The uncertainty about soil conditions (due to contamination from former activities), large spatial needs or the higher construction costs (around 7% percent higher for inner city sites[85]) are reasons to add to the more difficult marketability of dense infill locations.

80 Glaeser, 1999 pp. 254-277.
81 Castells, 2000
82 Glaeser, 2010 p.36
83 Fainstein, 2001, p. 1
84 Breheny, 1995a
85 Building Magazine's Cost Model. www.building.co.uk [last accessed 03.10.12]

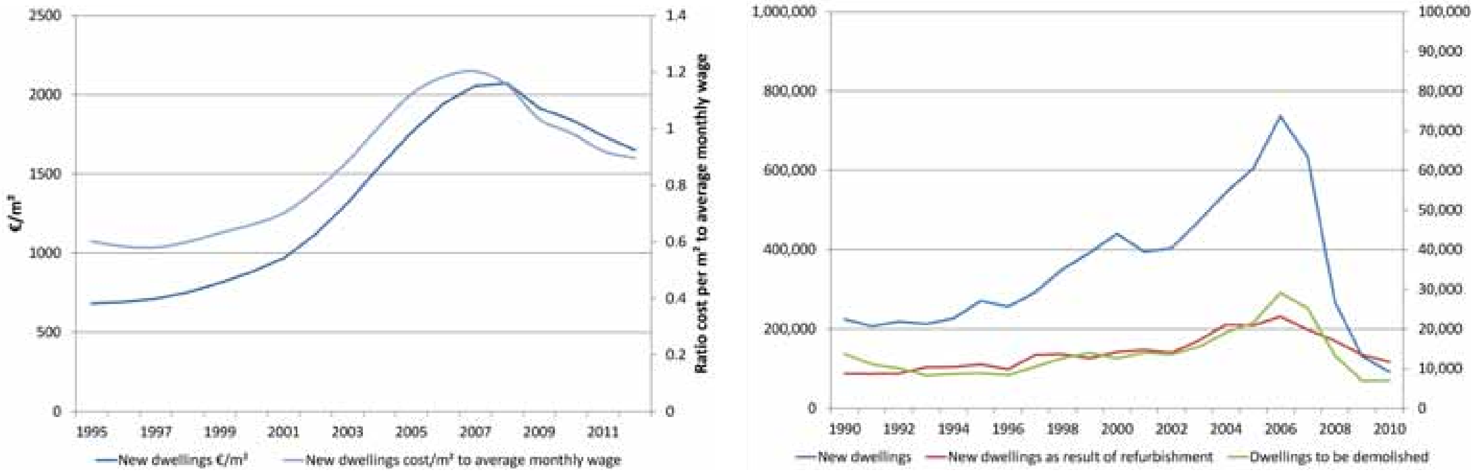

Fig.3-20 Left: Evolution of housing cost and affordability (data: National Institute of Statistics) Right: Housing construction activity by sector (data: National Institute of Statistics)

One of the most debated issues of urban containment from an economic perspective has been its effect in housing prices. According to liberal economists, it has been largely demonstrated that planning control and preservation policies have resulted in increased housing prices[86]. A series of evidences are displayed to illustrate how substantially land cost has increased since the implementation of constraining policies in UK in the 1960s. The logic says that the less land is available in the market the more expensive it gets and, consequently, the final housing price will need to absorb the extra cost of land purchase. However, the argument has been disputed, first theoretically, by arguing that is not the price of land that influence housing cost but conversely, the land becomes expensive because the current price of housing is high[87]. Moreover, the effects of deregulatory policies in the 1990s have provided empirical evidences to cast serious doubts about the direct correlation between available land for urbanization and housing prices. In the late 1990s massive chunks of land were designated as suitable for development in Spain, deregulating policies and tax incentives spurred a frenetic house building activity. Far from improving housing affordability, it became an investment commodity whose price skyrocketed in a short period (fig. 3-20), inflating a bubble with painful consequences in its aftermath. Therefore, the economic argumentation in favour of laissez-faire can be strongly questioned. Planners defend that, even if it were true, housing cost would be a regrettable but acceptable consequence of broader urban policies that seek to improve the city and its relation with the environment[88].

86 Evans, 1988
Ehrman, 1988
Simmie, 1993
Hall, 1973
Cheshire & Sheppard, 2002
Pennington, 2001
87 Neuberger, and Nicol, 1976
Ball, 1983
Grigson,1986

3.5. Learning outcomes

In summary, there is a number of evidences that suggest certain correlations between urban form and sustainable development targets. Density and compaction have monopolized much of the discussion but this is not a novelty since they have been widely used as indicators to analyze, study and control urban form since the second half of the 19th century[89]. However, density alone may be a poor instrument, given the variety of forms it may adopt, the different perception that people may have on it (not the same density may be deemed as bearable in China as in North London)[90] and the initial spatial characteristics of the city. Densification of a scattered city may have a greater cost than to apply containment measures in a more compact place, to the extent that it may be unfeasible in a given context. Extensive research is trying to fill these gaps and to provide further evidences to test and verify the claims that have been described in previous paragraphs[91].

The following attributes have been consistently observed as connected with urban compactness so far:

- Efficient transport systems, which benefit from the spatial concentration of potential passengers and proximity of core destinations
- As a result of the previous point, together with reduced commuting distances, the energy spent in transport is potentially lower in compact cities
- High density allows to accommodate urban activities in a smaller area, therefore more Greenfield land can be preserved unaltered

88 Breheny, 1995a
89 Berghauser Pont & Haupt, 2010
90 Hagan, 2001 p.184
91 Ng, 2010 Forman, 2008 Pedersen, 2009 Jenks and Dempsey, 2005

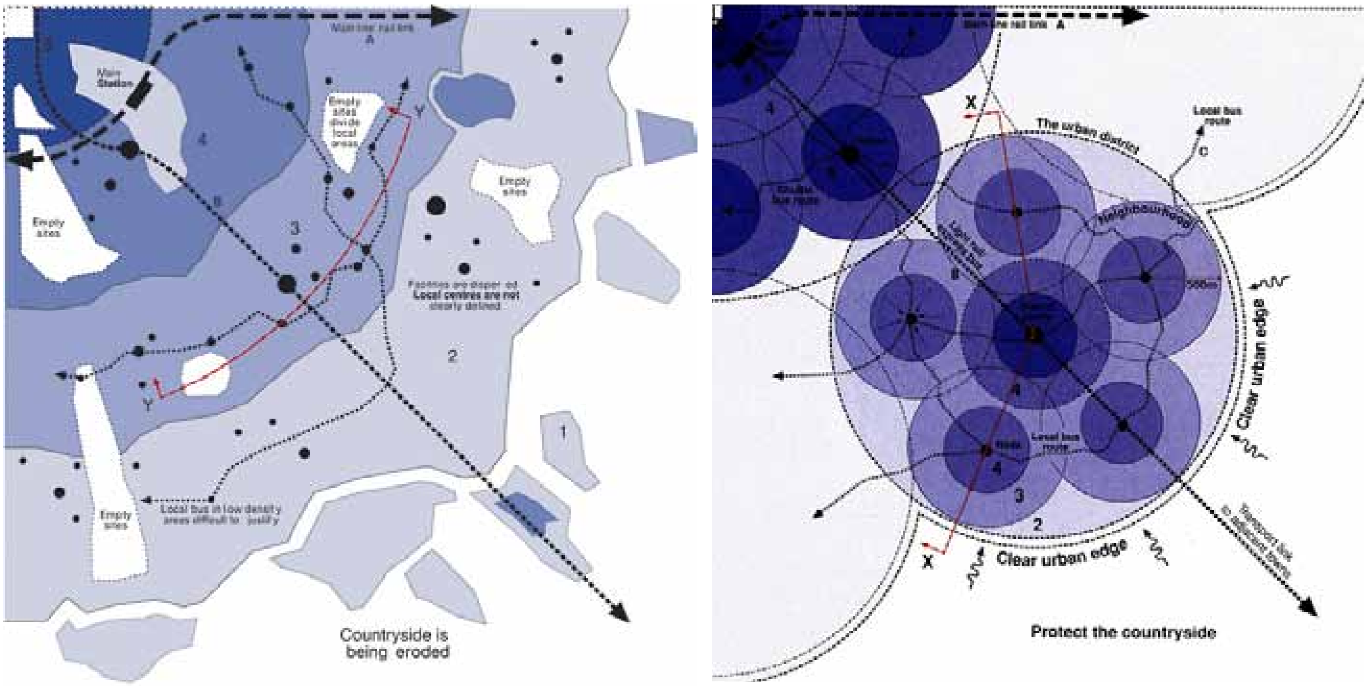

Fig.3-21 Dispersed Concentration by means of new centralities versus the uncontrolled erosion of the countryside (Urban Task Force, 1999)

Likewise, the following issues are potentially worsened by the effect of compaction:

- Traffic congestion and derived pollution
- Limited solar access inside and outside buildings
- Anthropogenic heat that is released from buildings and it is trapped within the urban fabric
- Long wave radiation from sealed surfaces that contribute to increase the urban heat island effect
- Increased dependence on external resources, including water and food supply
- Building typologies are limited and housing type is determined by affordability (as single family houses may not be possible or they become too expensive)
- Top down decisions may raise opposition from citizens

A third category of issues has not yet been positively demonstrated as related to urban form, although there are theories that suggest they might:

- Mixture of activities and uses
- Social integration
- Electricity, heating and cooling loads of buildings
- Economic prosperity

Although positions have been simplified as completely polarized in order to synthesize arguments and counterarguments, there is a compromise between opposites that rejects any extreme concept of urban form. Indeed, consensus is being mounted upon the idea that, rather than speaking of the ultimate sustainable urban form, there should be "a number of sustainable urban forms which respond to a variety of existing settlement patterns and contexts"[92]. More recently, alternative formulations have gone beyond the centralist/decentralist duality and urban morphology theories have been revisited and updated. Dispersed concentration[93] or polycentric cities[94] are concepts that refer to a compromise between containment and growth in which new centralities are encouraged in locations with good access by public transport. A similar notion inspired the Transit Oriented Developments[95], an idea associated to terms such as "urban villages" or "traditional neighbourhood development" that, under the heading of New Urbanism proposed the development of areas close to public transport nodes, applying moderate densities (25-40dwellings/ha) and a mixture of uses to promote walking[96] in somehow picturesque environments.

It all seem to verify the unseemly difficulties that the attainment of a theory on good city form entail, just as Kevin Lynch had foreseen at the beginning of this chapter. This research aims to provide some further insights in this matter by analyzing the effect on the city after important urban infill transformations have been carried out. The following chapters will consolidate the theoretical background and the state of the art in more specific elements of urban analysis.

92 Jenks et al, 1996 p.345
93 Frey , 1999
94 Hall and Payne , 2006
95 Calthorpe , 1993
96 Buxton, 2000p. 54

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CHAPTER 4

BUILDINGS’ ENERGY AND URBAN FORM

4.1 The analysis of cities as open systems

The city as a organic system has been a central analogy in urban theory since the 1930s. Alexander defined the city as sets of systems which were composed by physical components and non physical attributes. According to Dury[1], a system can be defined as a structured set of objects, attributes, or a combination of both, which was aligned with Alexander’s idea. Furthermore, cities are open systems, which involve flows and transfer with their surroundings[2]. Urban activities require of energy, matter and water from external sources and sinks for the waste that is generated. Urban ecology uses this analogy with natural systems to extrapolate principles and concepts from scientific ecology to understand the processes and relationships between the city and the environment. It aims to illustrate the dynamic properties of the city by quantifying the exchange of energy and matter with external systems. The hypothesis presupposes that if the input supplies and excess waste can be accounted, then it would possible to measure impacts, extract trends, or to establish the logic of cause-effects to design mitigating strategies.

In the 1950s, Eugene Odum broadened the ecosystem definition to include its associated biotic community[3] . The new definition meant a new approach in scientific ecology but it also set the ground for a new perspective in urban studies. The original concept of ecosystem alluded to organized units which “*progress towards equilibrium which may never be attained but to which approximation is made whenever the factors at work are constant and stable for a long enough period of time*”[4]. The area of interest was merely that of the physical system of study (the pond or the meadow) but not its surrounding environment. Odum elaborated on this theory, but he considered that ecosystems were, as all living organisms, open systems. As such, they need a constant exchange of matter and energy with their surroundings to develop their basic activities. The boundary of study should then be extended so as to include all the elements that interact and support the activities undertaken by the system, either by supplying the necessary energy, matter or by receiving the processed energy and materials.

1 Duty, 1981quoted by Douglas, 2011
2 Douglas, 2011
3 Odum & Warret, 2005
4 Definition by sir Arthur Tansley (1935) quoted in Odum, 1997

The specific characteristics and magnitudes of the flows of energy and matter are referred to as metabolism. In a natural ecosystem, autotrophic and heterotrophic[5] components are balanced so that cyclic processes can be sustained over time. The energy and matter produced by the system are enough to allow its development and the metabolic activity is relatively low. This means that most inputs can be synthesized within the ecosystem and the output is relatively low. It can be easily assimilated by the environment.

Seminal studies on Urban Metabolism, carried out by Abel Wolman in the 1960s[6], revealed the extent to which cities (in this case American cities) were absolutely dependant on external inputs and how their inability to efficiently convert those supplies ended up in enormous waste. The huge metabolic rate by each unit area was revealed as the main difference between natural ecosystems and the city. According to Bettini, there are other two important differences[7]:

- The urban metabolism implies special materials (metals, plastics...) in addition to the basic ones
- The biogeochemical processes within the city generate contaminant waste

Wolman pioneered the extrapolation of metabolic flow to human activities. Starting from national data, he determined the metabolism of an hypothetical American city of one million inhabitants and put figures to the stress caused by cities on the natural environment. He considered three main inputs : water, food and fuel and three main outputs: sewage, solid waste and atmospheric pollution. The magnitude of the resulting figures raised concerns and a series of studies in real cities were undertaken in the 1970s.The study of Brussels was the first application of urban metabolism to an actual city[8]. The UNESCO Man and the Biosphere program prompted a worldwide project in which cities were to be considered and studied as ecological systems. The most detailed work was elaborated for Hong-Kong. The coincidence of city and state boundaries facilitated the compilation of data[9]. Parallel

5 Autotrophic: shelf-nourishing components which can process energy from light and simple organic substances (e.g. plants by photosynthesis) Heterotrophic: other-nourishing components which utilizes the materials synthesized by the autotrophics (e.g. animals)
6 Wolman, 1965
7 Bettini, V 1998
8 Duvigneaud & Denayeyer-De Smet, 1976
9 Newcombe at al., 1975, Boyden et al 1981

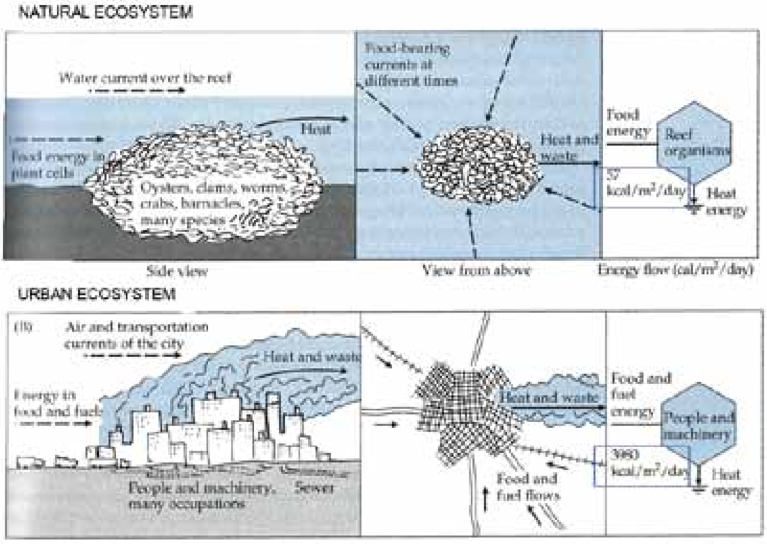

Fig.4-1 Flows and metabolic rate of natural ecosystem versus an urban ecosystem (Odum & Warret, 2005)

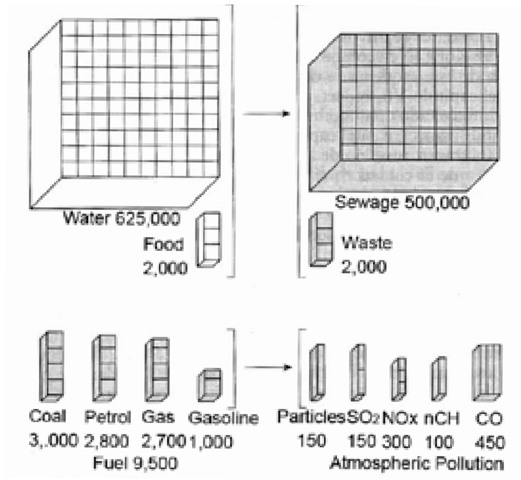

Fig.4-2 The urban metabolism of an imaginary American metropolis (Wolman, 1965)

studies included some other sixty cites including Paris, Rome, Tokyo, Munich or Barcelona. This program aimed to promote research on the complex interrelationships between urban settlements and their hinterland[10] by measuring the flows of food, energy, materials, people, information and other elements. The flow assessment was also complemented by the analysis of the psychological effects of urban pressures upon population.

In parallel to this program, Howard Odum (brother of Eugene) initiated a different line in urban metabolic studies. He devised a specific notation, borrowed and adapted from electric circuits, to describe the interactions between the ecosystem's components via energy flows. He introduced the terms "emergy" and "transformity". The former is described as all the available energy that was used in the work of making a product in units of one type of energy whereas the latter refers to the energy of one type required to make a unit of energy of another type. The method is based on the reduction to all flows and processes in the system, including economic, to their emergy equivalent units and the representation of the interactions by the specific notations. Although this theory has had a limited influence, research is kept up at University of Florida. It delivered environmental accountins in areas such as Thailand, New Guinea and South America[11] as well as metabolic studies in Taiwan[12].

During the late 1980s and early 1990s research in urban

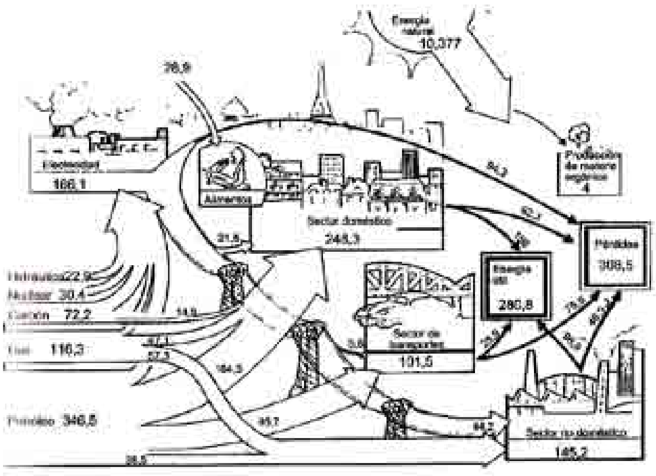

Fig.4-3 The urban metabolism of Paris (reproduced from Salvador Palomo,2003)

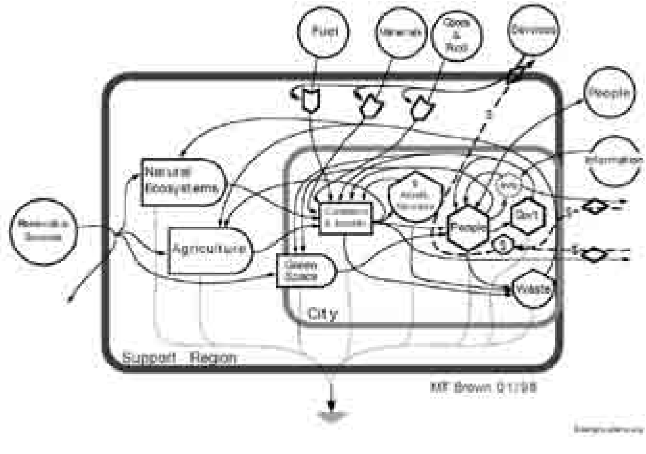

Fig.4-4 Energy flows in a generic city and its supporting region according to Howard Odum notation system (emergysystems.org)

10 Boyden & Celecia, 1981

11 emergysystems.org

12 Huang, 1998

metabolism was scarce. The complexity of the variables, divergence in scales of measurement and the inability to account for behavioral variables[13] limited the scope and interest for the subject. Energy agencies kept regular accounts on energy consumption, mainly at national levels[14] and several reviews of older studies in cities such as Hong Kong, London or Sydney were the only niches of that period.

In the last decade, there has been a renewed interest in urban metabolic research. Since year 2000, major international organizations have created standards for material flows accounting (MFA) at national scales. In 2001 the European Commission released a methods guidebook for its state members on the matter [15] which was followed by an equivalent from the OECD[16] and the UNEP[17] in 2003[18], which focused on urbanization. Apart from setting a common framework for statistics and information, these documents aimed to relate the impact of economy upon the environment and, conversely, to analyze the contribution of the environment to national economies.

The current approach tries to extend the traditional metabolic analysis beyond a resource flow perspective to incorporate aspects of livability and environmental quality. The amount of resources and energy have to be also translated into benefits for society to demonstrate the practical meaning of sustainability. The flows of capital and information are included as inputs that fuel and determine urban activity. Likewise knowledge and services have to be considered as outputs resulting from the transformation and synthesis carried out within urban systems. This adds a further layer of multidisciplinar complexity to the subject which has been enhanced by the adoption of complex systems sciences, which have the potential to integrate anthropogenic and natural activities into one framework[19].

4.1.1 The Entropy Theory

In the current global economy, cities´ success is primarily based on the increase of resource pumping. In order to operate its activities, the city requires a constant supply of energy, of which only a small portion is transformed into work (or services) while the rest is dissipated as heat or waste. Consequently, in this global competition, there are two options to attain success. The first option, the current paradigm, is to increase pressure upon natural reserves to increase the level of production thus subsidizing the inefficient performance of cities. The alternative to this is to sustain the economic balance by improving the organizational structure

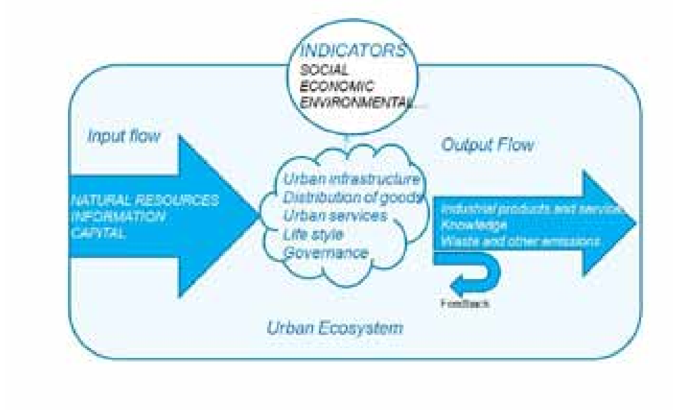

Fig.4-5 Current approach to urban ecology, linear metabolism and weak feeback

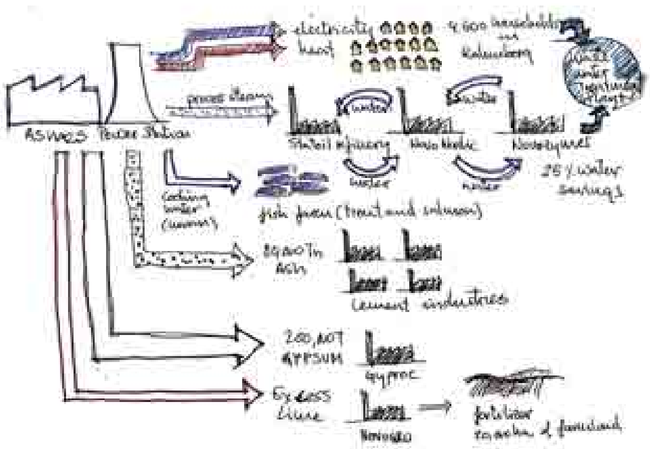

Fig.4-6 Example of circular metabolism in the industrial system of Kalundborg Denmark. Up to 20 industrial firms cooperate to exploit each other's waste and by-products

(complexity) in such a way that the urban system becomes more efficient.

The relation between organization and energy can be analyzed by using thermodynamic laws:

- The first law states that energy may be transformed from one form into another, but it is never created or destroyed.
- The second law states that no process involving an energy transformation will occur unless there is a degradation of energy from a concentrated form into a dispersed form. Some energy is always dissipated into unavailable heat energy as no transformation can be 100% efficient.

The degree of energy dissipation is measured by entropy, which, by definition, is always higher than zero. The entropy of a system is like the efficiency factor in a boiler, a value that indicates the proportion of energy which is transformed and the proportion that becomes heat. If the entropy is 100% then all the energy supplied is wasted, which in practical

13 Douglas, 1983
14 See, for instance the publications from the Lawrence Livermore National Laboratory for US data (www.llnl.gov)
15 Eurostat, 2001
16 Organization of Economic Cooperation and Development
17 United Nations Environment Programme
18 United Nations, 2003
19 Bai & Schandl, 2011

terms would mean the thermodynamic death of the system[20]. Low entropy is only possible in highly organized systems that have efficient "dissipative structures to pump out the disorder"[21]. Conversely, to maintain order, some energy transformation is always necessary thus entropy is increased. Ilya Prigogine explained this apparent contradiction on his studies of non equilibrium thermodynamics in open systems. He theorised on how living systems could organize themselves to maintain an open, far-from equilibrium state. This is possible by two reasons: first, although the quantity of energy may decline in successive transfers, the quality of the remainder may be greatly enhanced[22] and, secondly, because they are open systems (i.e there is an exchange of both energy and matter with the external environment) they can attain a negative entropy (high order) by increasing the entropy (disorder) of surrounding environments. This could be illustrated by a Photovoltaic panel, which transforms a dilute energy form (sun's rays) into more concentrated energy form (electricity) thus enabling negative entropy. However, the production process and the transport of the panel will contribute to increase the entropy in external environments: the quarry where the silica was obtained, the plant where it was manufactured, etc... For this reason it is important to calculate, not only the entropy incubated within the system, but also that which is poured to other systems. In the city, it implies the consideration of the embodied energy of all urban activities as part of its metabolic account.

Therefore, the reduction of the current high dissipative structure of the city as open system is only possible by increasing its efficiency, either decreasing the energy it absorbs or increasing the order sustained by the same energy inputs. The question is then, how can the city become more efficient?

One way in which the city can reduce its entropy is by maximizing positive feedbacks, this is, if by recycling the waste that is generated back into the system to produce new effective work (figs. 4-5, 4-6). The energy required for feedback rewards is lower since it does not imply the use of prime materials.

Another, more unconventional, approach focuses on the reduction of entropy by increasing the complexity and organization of the information within the system.[23] Biological organisms have evolved from the simple cell, which could only do basic functions, to humans, which can undertake many kinds of physical and intellectual work by only consuming some 150w (like a bulb). This level of efficiency was possible by the development of complementary components which develop specific functions (organs, tissues…) In a natural ecosystem, the existence of complementing components or species is essential for survival as that is the base for symbiosis. All species have an important function and if one gets extinguished the whole chain can be endangered. For this reason, it is desirable the existence of many species and varieties which develop both general and specific functions. This variety is normally referred to as biodiversity, and it can be measured using dominance indexes such as Simpson's or Shannon's[24]. BCN Ecologia applied this former formula to urban studies to calculate the complexity and organized information within the city. Their hypothesis suggests that the information embedded in the urban fabric is proportional to the concentration of different activities in that physical structure (lawyer, doctors, pubs…). The concentration of professionals and activities would enhance synergies and knowledge that would result in high quality information which would ultimately enable a more efficient use of the metabolic inputs of the city.

20 Bettini,. 1996 p112
21 Odum, 1997 p.81
22 Ibid. P.82
23 Rueda, 2006

4.1.2 Urban Ecology: Useful outcomes

Urban ecology has been instrumental in advancing a new scope of urban analysis in the last half century. During its earlier years, it was intimately adhered to environmental sciences, with little projection to other fields. However, during the eighties, it took a greater dimension, partly due to the relevance acquired by energy flow analysis after the oil crisis, and partly due to the acceleration in the urbanization process. The publication of Abel Wolman's study in 1965 had presented cities as intensive degraders of natural resources. They were black holes that needed a constant energy and fresh water supply while returning waste and pollution to the environment. This study put the focus of environmental policies on urban systems, despite the broad definition of city that was implied in metabolic studies, which included both urban and rural territories, for the data was available for political boundaries. Nevertheless, as many human activities were located within cities, the association became mainstream and ways to minimize urban intake were sought after.

However, as Lionel March pointed out, modest goals and vague theories may be more effective than all-embracing formulations that "take on the whole world without having achieved even one small but sure step forward in our understanding"[25]. Knowledge on urban metabolism must grow by the appreciation of well bounded issues to then stretch to wider and more complex relationships. This thesis is primarily focused on energy aspects and the relation with urban form. Therefore, it will first look into those factors which most affect the energy demand to undertake urban activities that can be influenced by urban planning and design.

Although metabolic studies had revealed a diverse range of flows, energy efficiency had become paramount since the oil crisis of the 1970s. In following decades, the priorities

24 Odum, E.P. 1997 p. 63
25 March, 1972

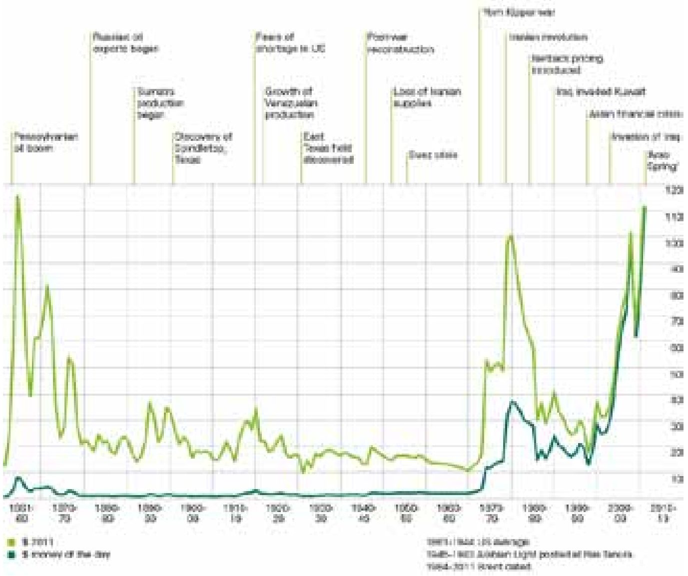

Fig.4-7 Fuel price fluctuations since 19th century (source:BP)

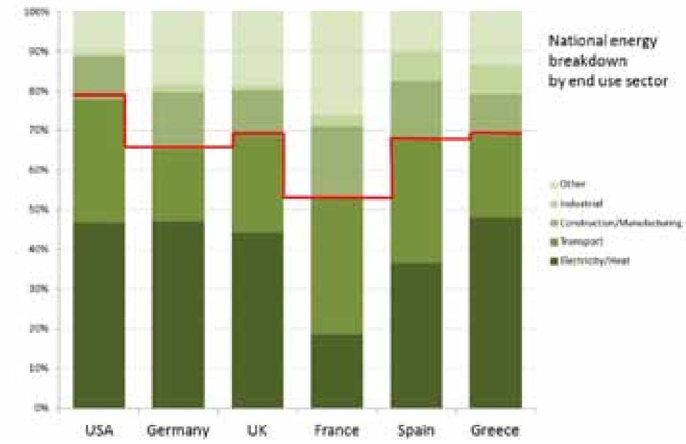

Fig.4-8 National energy breakdown by end use sector (data: WRI)

of urban policies and research paid close attention to fluctuations in oil price. When the price was low, as it was during great part of the eighties and nineties, running costs were affordable and the undergoing transformations from production to service centres made cities neither concerned nor willing to take special precautions concerning energy use **(**fig 4-7). Geopolitical events, at the turn of the century, anticipated a change of trend and fuel prices started a new and steady rising trend. The combination of high fuel price and a greater environmental awareness raised the concern about fossil fuel dependence. In countries such as United Kingdom, Germany or Spain, transport, electricity and space heating accounted for up to 50% of their overall CO_2 emissions (fig. 4-8). A great share of this demand could be related in one way or another to processes and activities occurring in cities, which inspired estimates about the influence of planning in energy demand. Some authors have subscribed that up to 70% of delivered energy was directly or indirectly determined by land use planning[26].

26 Owens ,1992 and Williams et al, 2000

4.1.3 Opportunities and barriers in urban energy analysis

Numerous studies have tried to discover correlations between urban attributes and energy use. The analysis of formal characteristics was a logical starting point for the wider urban debate had been dominated by issues of morphology for several decades. Density, sprawl, containment or typological researches were familiar concepts for the students of the city. Urban ecology would provide the framework to establish a hierarchy of priorities regarding material flows and resource consumption. Metabolic studies had shown the patterns of energy demand in cities and the proportions by end use. In the absence of local data, national figures were also available to confirm the large dimension of sectors such as transport (15 to 35% of total energy demand) or domestic buildings (around 40%), which were demonstrably influenced by urban form (fig 4-8). The hypothesis was that if a substantial amount of the energy demand was likely to be determined by spatial aspects, then it could be possible to induce energy savings by optimizing the urban form. Two major fields of study emerged: on the one hand, transport energy studies, which were fed from surveys and a broad tradition in transport modelling and, on the other hand, thermodynamic studies, which analyzed patterns in buildings, especially for heating and cooling purposes. As buildings' performance is closely dependant on climatic conditions, a third line of research had to explore the effects of urbanization in urban microclimates: the heat and cool islands that had been brought out in the seventies[27] . A typical research in energy and urban form would draw an hypothesis on the connection between one key demand (e.g. domestic heating or transport fuel) and one or various morphological characteristics of cities (density, distance to city centre, degree of compactness/ dispersion). The analytical work would seek to demonstrate that connection by comparing energy consumption estimates against morphological indicators, either empirically or by means of computer models. If the correlation were consistent, a regression analysis would be carried out to obtain the elasticity[28] between the two factors. The results could be then used to inform policies and projects. However, despite the increasing wealth of data and studies, few of these have transcended theoretical and academic circles. This could be explained by a number of reasons:

- Policy making are seldom inspired by one only particular subject; therefore energy efficiency alone is unlikely to guide planning decisions
- There may be underlying trends that offset the efficiency of a policy in the long term (for instance great improvements in buildings' insulation levels may do

27 Oke, 1987

28 Method used in econometrics. Initially aimed to calculate the correlation between price and sales, it is defined as the proportion between sales and price percentage variations to foresee how sharply or steadily the sales would drop as the price increases.

building compactness an irrelevant aspect in the future)

- Non spatial aspects may have an stronger impact than physical transformations (e.g. behavioural patterns, pricing policies...)
- The lack of continuity between the various scales has been a critical issue in most of studies. They typically refer to a single scale of reference (region, city, block, building...), the choice of the reference dimension determines which factors have a greater influence at that level but this is not necessarily consistent across scales. A building that is considered very efficient when it is analyzed at local scale may present different results when its effects on neighbouring buildings (overshadowing, wind turbulences...) or in the region (inappropriate location, remote destination...) are taken into account.

The difficulties and high complexity of urban energy analysis does not make it less necessary, at contrary further research is much needed to equip planners, designers and policy makers with legible, manageable and informative instruments that can be applied at various scales and stages of city making process. In this research, three main factors will be discussed in detail:

- Urban climate, which defines the scenario to where people interact and to which buildings respond
- Buildings performance, which are the main energy receivers in cities
- Transport, which affects both urban quality and the metabolic performance of cities

4.2. The Urban Climate

It is well known that urban buildings are exposed to climatic conditions that are distinct from nearby rural areas. This difference will eventually affect the energy that is required to maintain the internal living and working environments within comfortable parameters, since all buildings are responsive to their surroundings in some degree. Moreover, buildings also play an active role in the formation and intensity of urban microclimates. Their location, morphology, materials and functions within the urban fabric contribute to gradual variations in temperature, wind or humidity over the city. Some of these alterations induced by urbanization may have a positive effect in certain places, during a certain period or season of the year, for instance raising air temperature in cool winters, but the observation of this phenomenon at global scale has identified it as a key issue in the metabolic and environmental performance of cities.

City climate is primarily moulded by the geographical location. Latitude defines sun position, day length and solar radiation. Altitude and proximity to the sea affect wind patterns, humidity and the intensity of storms and rain. Other geographic elements, such as the presence of a mountain range or a river valley will do their bit to further modify the climate at the meso-scale. The closer the scale gets to the city, the stronger the city itself influences climatic conditions. This is mainly due to the different ratio of surface-to-atmosphere fluxes of energy, water and mass occurring in urbanized respect to non urbanized territories[29]. Urban climate results from the combination of surfaces with different attributes and the intense human activity. They affect the flux exchanges and, consequently, the atmospheric variables (temperature, wind, evaporation, pollution...) which are related to them. The nature and extent of these climatic modifications depend on the global weather, presenting seasonal and diurnal patterns, as well as urban morphology (urban canyon, materials, density..). Evidences about the impact of city form in local climate are abundant and are well documented. Thanks to current technology (i.e. satellite imagery, sensors, weather stations...) it is possible to illustrate these connections with a vast display of graphical and numerical data.

4.2.1 Urban Heat Island

The Urban Heat Island (UHI) effect has been a widely studied phenomenon. It is defined as “the characteristic warmth of a settlement compared with its surroundings”[30] that occurs when “rural cooling rates and greater than urban rates”[31]. A gradual increase in temperature can be noticed when moving from a rural area to the city centre. In reality, since cities are not homogenous, variations in temperature tend to present discontinuities, associated with changes in the urban fabric. The physical processes behind the UHI are basically those involved in the surface-atmosphere interface which are altered by the presence of features which are genuinely urban:

- **Incoming solar radiation.** Urban surfaces have, in general, a low albedo (0.15 is an average value for mild-latitude cities in snow free conditions[32]) which enhances heat absorption and the subsequent increase of surface temperature, especially in roofs and large parking lots with high exposure. In addition, unobstructed façades provide further surfaces to harvest the heat from solar radiation.
- **Incoming long wave radiation.** Pollution, greenhouse gasses and aerosols reduce the visibility in the urban boundary layer[33] hence the atmosphere emits more downward infrared radiation and limits the heat dissipation by long wave radiation.
- **Outgoing long wave radiation.** The heat that is absorbed during the day can be partly released by radiation towards cooler surfaces. The sky provides the most favourable opportunity to dissipate excess heat and thus

29 Grimmond, 2011
30 Oke, 2011
31 Leung & Lee, 2010
32 Oke, 1987
33 Urban Boundary Layer (UBL) A plume formed above the city, bent leeward, where the climatic effects are still influenced by the presence of the city

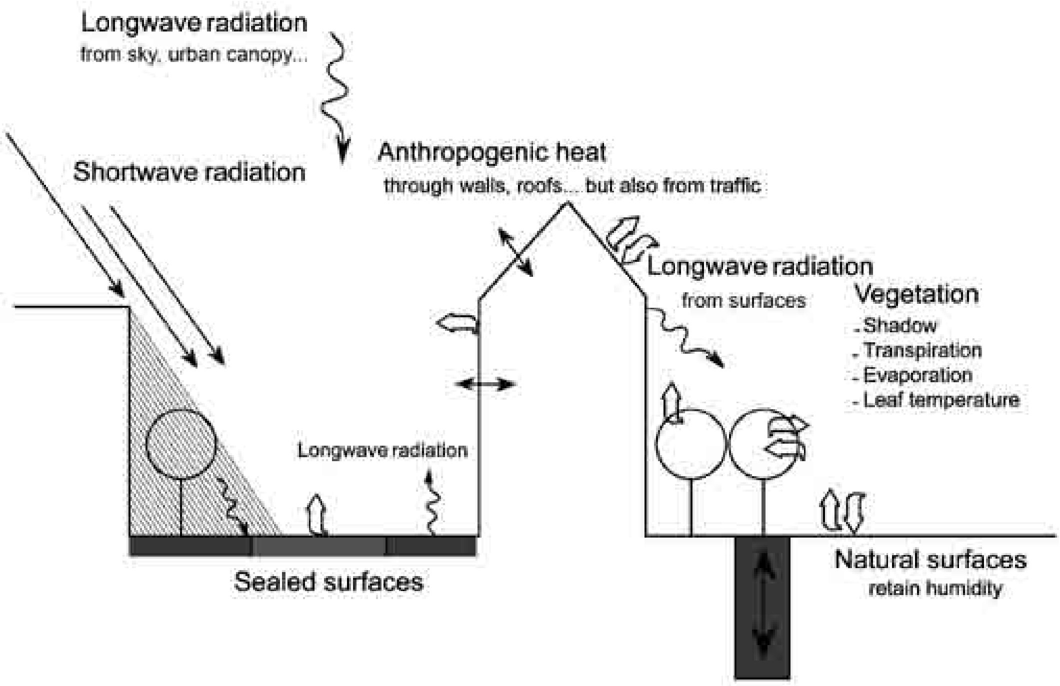

Fig.4-9 Diagram of the main flows that shape an urban microclimate (after Bruse,2007)

to reduce surface temperature, especially at night and under clear sky conditions. However, the urban canyon (streets confined between continuous building frontages) prevents a wide view of the sky and, consequently, the potential of night radiative cooling is reduced.

- **Convection**. Winds are dragged down by the roughness of the urban profile, which means that the average air velocity in the urban area tends to be lower than in rural unobstructed surroundings. The English CIBSE Guide A[34] estimates an standard reduction of 30% in wind speed between the open countryside and an urban context for the same regional climatic conditions. At street level, wind flow patterns are much more diverse and almost unpredictable, due to the turbulences caused by buildings that block, divert and enhance air movement. The shelter provided by urban roughness and buildings will also diminish the potential heat losses by the effect of convection.
- **Evaporation**. Roads and pavements are normally sealed and waterproofed in urban environments. Rainwater runs directly into the sewage systems and thence the superficial ground layer remains dry in the absence of rain. In natural soils, rainwater remains trapped and stored in the superficial porous system, in warm weather this water content starts to evaporate to the atmosphere producing a cooling effect in the immediate ambient.
- **Heat storage**. Typical urban surfaces (concrete, cement and the likes) tend to have a moderate to high thermal storage capacity, which means they have a great potential to absorb heat during the warmer hours of the day and to release it, steadily, during the night. It produces a softening effect in ambient temperature. Actually, natural soils' storage capacity is not much lower, due to their moisture content. However buildings have a larger vertical surface (i.e. walls and façades) which means an additional storage capacity compared with green areas.
- **Anthropogenic heat**. Human activities generate heat. Part of this heat is purposefully sought after to offset otherwise low temperatures, it is the space heating. A remaining heat output is inherent to every energy transformation process. Part of the energy used for lighting, transportation, cooling or manufacturing does not produce the aimed work but it is transformed into heat. The anthropogenic heat, from human activities, is emitted to the urban environment either by direct exhaustion (exhausts, chimneys...) or indirectly from buildings' interior (by heat transfer through their envelopes). The aggregate heat waste is a considerable contributor to the urban heat island. According to measured data, anthropogenic heat could reach over 1000 watts per square meter in dense, developed cities during cold periods and around 100 watts in warmer seasons[35].

34 CIBSE, 2006

35 Ichinose et al, 1999

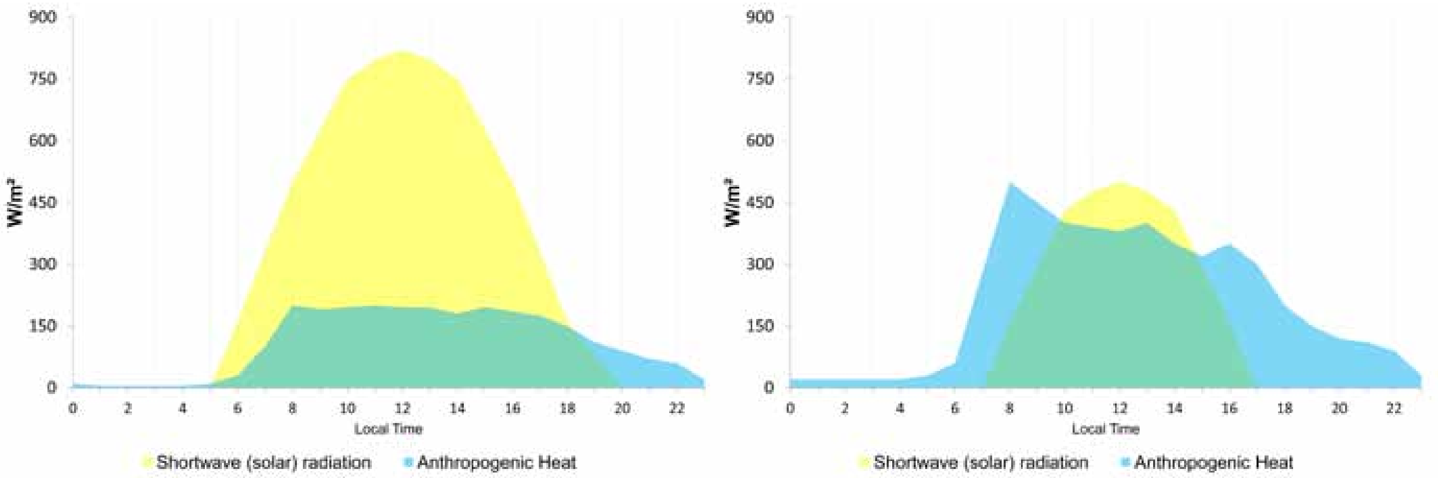

Fig.4-10 Surface heat budget in central Tokyo for shortwave radiation and anthropogenic heat in typical summer (left) and winter (right) days (after Ichinose et al, 1999). Although absolute values of human generated heat are higher for winter, their impact in energy consumption may be stronger in summer as there is an additional load to offset by cooling systems

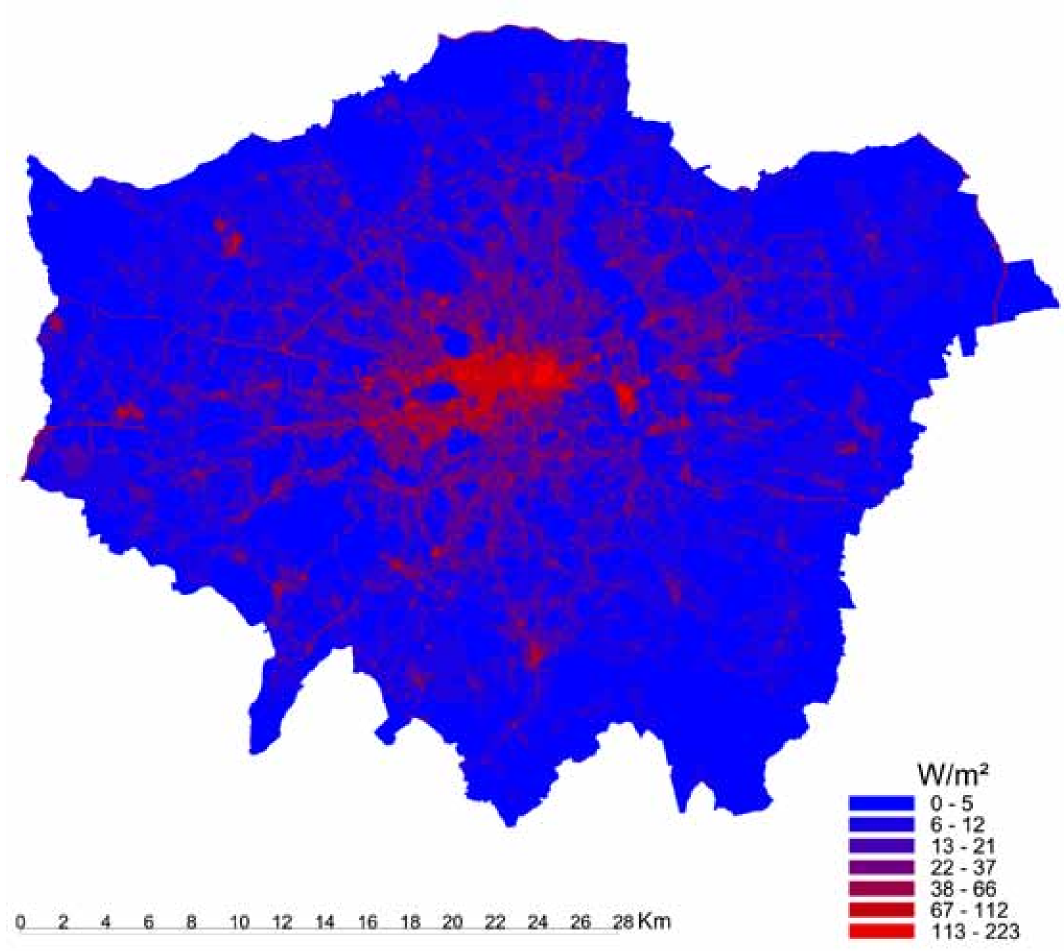

Fig.4-11 Anthropogenic heat emissions in Greater London, annual average (data generated with Greater QF software, Department of Geography King's College London. Processed and plotted by the author in GvSIG)

Fig.4-12 Sky view factor for Westminster area in London. A value of 1 represents unobstructed view (Lindberg & Grimmond, 2010)

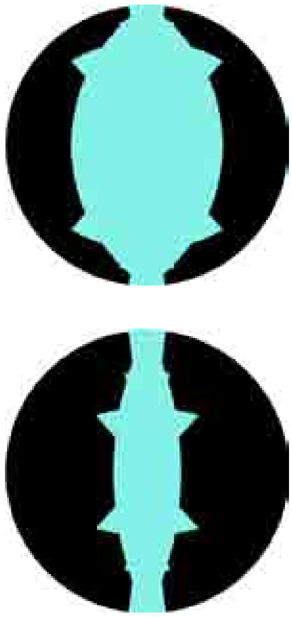

Fig.4-13 Sky view for different building street width to building height ratio. Top: typical urban street, W/H=1 Bottom: low density area, W/H=3

It can be noticed that all the aforementioned processes are dynamically and spatially changing. As a consequence, the UHI intensity will also evolve according to time and location within the city. A combination of conditions can either decelerate urban fabric's cooling rate or accelerate heat inputs thus resulting in warmer temperatures being kept for longer. If this happens when diurnal temperatures are above comfort, it will most probably result in an additional building cooling demand. The UHI can provoke differences up to 12K between relatively near spots (fig.4-17).A clear sky, the absence of wind and a densely populated urban environment are favourable conditions to sharpen its effects. The thermal gradient becomes more pronounced during summer cloudless nights. In this scenario, rural areas can take full advantage of the sky as a heat sink, whereas the urban canyon will obstruct part of the outgoing radiation flow. The degree of obstruction will be determined by the proportion of street width to building height. Tall structures will block a greater portion of the sky thus undermining the capacity to cool down street surfaces by night time radiation. In this case, the heat will be stored, causing temperatures to remain relatively stable. Conversely, those same tall buildings obstruct direct solar radiation into the urban canyon, which may prevent a sharp increase in diurnal surface temperature. As a result urban temperature's daily fluctuation is, in general, softened by the effect of the geometry and materiality. The peaks tend to be less pronounced than in the open field although the average value increases in populated areas.

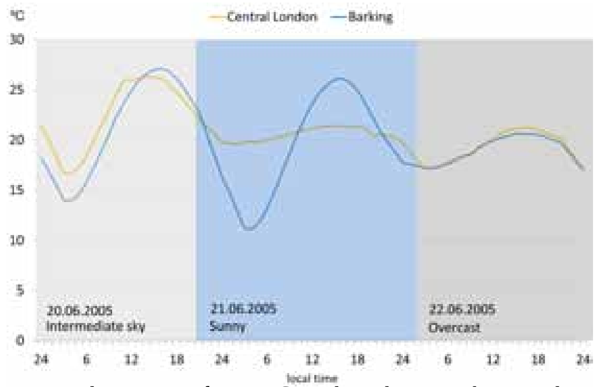

Fig.4-14 Daily variation of UHI in Central London. It can be noticed how the intensity of UHI is strongly determined by sky conditions (data from Meteonorm)

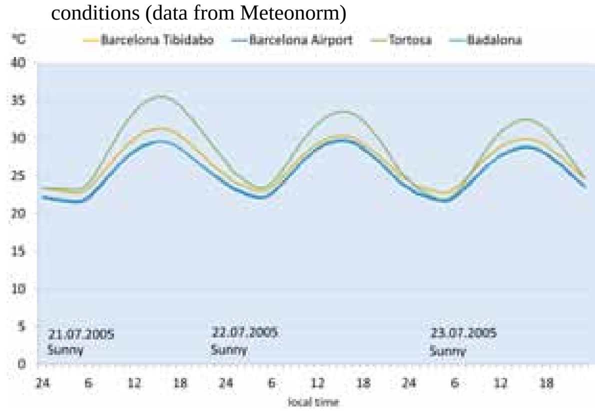

Fig.4-15 Thermal fluctuations for Barcelona show a different pattern as they decrease sharply at night, this can be explained by the location of the urban Weather Stations in the proximity of large parks. (data from Meteonorm)

4.2.1.1 Energy and Urban Heat Island

The dynamic nature of the Urban Heat Island makes it difficult to predict its intensity with accuracy. As with the climate, it is more convenient to consider a range of conditions and probability of occurrence rather than fix values. In those cases in which relative urban warmth is useful to reduce space heating, the underestimation of external temperature could be assumed as the actual scenario would be less demanding. However, in temperate to warm climates, or approximately between parallels ±40º and the equator, additional heat gains should be prevented for most building types during a great part of the year. An important portion of urban population is located in warm climates (Sao Paolo, Shanghai, Mumbai...). The additional cooling load that results from the interaction of urban form and climate should be specially looked after when planning and managing those cities.

Figure 4-16 shows an estimate of the energy implications of thermal variations driven by urbanization. Calculations were done for an imaginary piece of urban fabric that was located first in London and then in Barcelona. It consisted on a squared area of 500 by 500 meters with a Ground Floor Coverage around 40% and a Floor Space Index of 1.00 m^2/m^2. That gives a typical building height between 2 and 3 stories. It was assumed a mixture of activities in the area, including residential, retail, industry, some public facilities and offices. The simulations were carried out using the Urban Energy Index, the tool that has been developed as part of this thesis whose detailed specification will be given in following chapters. A first run was done using generic climate for each location, one for London and other for Barcelona, extracted from ClimateLite database[36]. A forecast for cooling and heating loads was produced and converted into primary energy use to add them up accordingly. For the second run, it was necessary to analyze the climatic data for London and Barcelona in order to include a realistic effect of the UHI. For London, two datasets were used: Barking and Central London. Both were obtained from Meteonorm[37] database. The air temperature hourly difference was calculated, giving an average annual increase of 0.5K for the central location, with peaks of -6K (the city being cooler than the rural location) and +6K (the city getting warmer) in different periods. In Barcelona, four datasets were examined. Stations at the city centre showed higher temperatures but they did not report the relative stability that was noticed in London(fig.4-14 and 4-15). It could be explained by the position of the stations, all of them located at the edge of large parks (the urban stations) or agricultural fields (suburban and rural stations). Finally, the same process was done as to obtain the hourly thermal variation between urban and rural temperatures in the region around Barcelona. The annual average increase at the centre

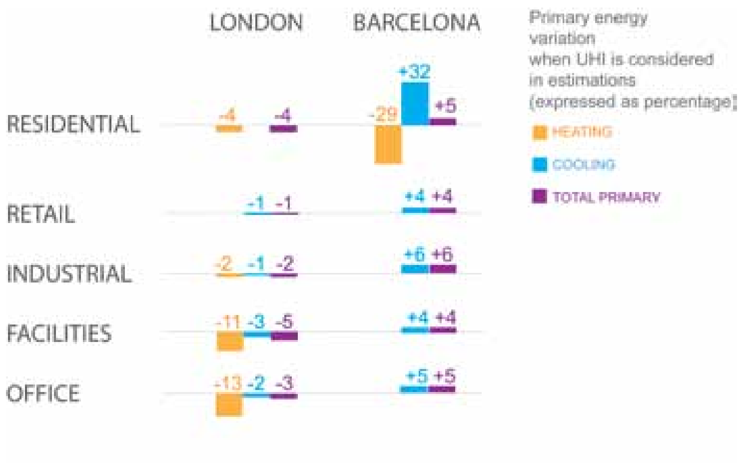

Fig.4-16 Variation in primary energy for heating and cooling when the effect of UHI is considered, for (imaginary) urban areas in London and Barcelona

respect to suburban locations was, in this case, 1.8K, with peaks from -3.8K to + 8.3K. The hourly temperature values in the original datasets were combined with the fluctuations identified in the climatic analysis, this is, they were either added or subtracted the equivalent to the urban-rural difference for each location. Energy calculations were performed again so as to obtain the estimated energy demand at the new scenario, in which the effect of the UHI had been considered. The results show a rather modest contribution for London, where the effect of the UHI allows space heating savings up to thirteen percent respect to the base case, therefore it seems to have an overall positive effect. In contrast, in Barcelona, which is eleven degrees southern than London and it is located in a Mediterranean climate, the impact in cooling was substantial, especially for residential uses, whose demand increased 30% due to the UHI effect. However, these were form specific results and further analysis proved that the level of impact of UHI in buildings' energy load was partly determined by spatial variables such as density or land coverage.

4.2.1.2 Urban Form and Urban Heat Island

It has been shown how urban warming was a local and occasional process, closely associated to weather conditions and to the form of the urban fabric. It can be inferred that for UHI to occur, certain spatial characteristics are necessary, yet the dynamics of urban temperature are still much determined by climatic variables. Despite the relative uncertainty, comparative analysis can unveil the interdependence between morphology and thermal spatial patterns in cities and regions. For this analysis, six European regions were selected to represent a cross section of urban models, covering different forms, climates and topographic contexts. Madrid (40ºN, 3ºE), Cologne (50ºN, 6ºE), Barcelona(41ºN,2ºE) London(51ºN,0.5ºW), Brussels(50ºN,4ºE) and Berlin(52ºN,13ºE) were the central cities of the selected regions. In relation with chapter 2 and

36 Climatelite software. www.bre.co.uk/page.jsp?id=996 [last accessed 30/10/2012]

37 meteonorm.com [last accessed 30/10/2012]

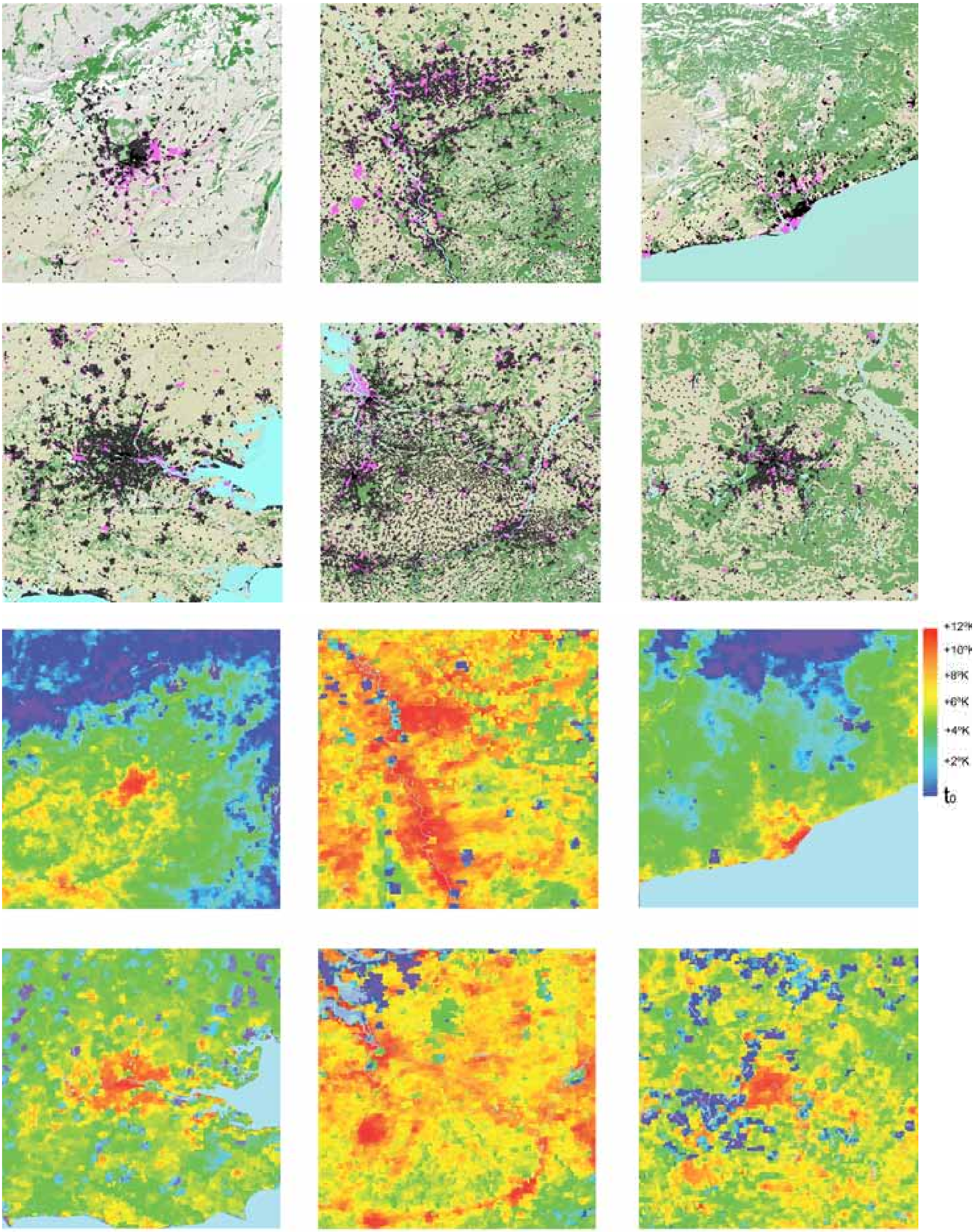

Fig.4-17 Land Cover (top) and Land Surface Temperature for a summer night (bottom) in six European regions. From top left, clockwise: Madrid, Köln, Barcelona,Berlin, Brussels, London (thermal data extracted from Satellite Modis, processed and plotted in GvSIG)

morphological classifications, these cities could be grouped in different ways, depending on the parameters that are considered:

- In terms of metropolitan structure, at least two regions could clearly adhere to the concept of polycentric metropolis (Cologne with Dusseldorf and Dortmund on one hand, and Brussels with Antwerp, Charleroi, Liege and the Walloon region on the other one). Madrid, Barcelona, London and Berlin present a more hierarchical structure with a core capital, of different sizes and densities though, and a highly centralized transport network that connects the capital with much smaller satellite towns.
- In terms of population dispersion, there would be a gradient from purely compact high dense cities (Barcelona and Madrid) to relatively contained but less dense models (Berlin and London in this order) and, finally, a continuous diffuse urbanization model (Cologne and Brussels)
- Using the terms and city types defined by classical classifications, Berlin and London could be identified as a star or radial model, Madrid and Barcelona as core, monolithic and compact examples, and finally Brussels and Cologne are close to the concept of constellation or galaxy.

To explore the intensity of Urban Heat Island in these regions, satellite images with information of land surface temperature were used. Satellite Aqua[38] transports MODIS (or Moderate Resolution Imaging Spectroradiometer[39]), an instrument that combs the entire globe on a daily basis to send images of the land and ocean surfaces in 36 different groups of wavelength. The specific product that contains data about land surface temperature is the MOD 11A2, which has a global resolution of 1 and 5 Km[40] and it can be downloaded from the Earth Explorer engine of the US Geological Survey. To visualize the data in a GIS software, it has to be reprojected first. There is an specific reprojection tool that is freely available after completing a registration form at the USGS site[41]. The data is organized in a grid format, each tile extends over a surface of 10 by 10 degrees. Despite their proximity, six tiles were needed to cover the six regions. It is important to point out that MODIS can only retrieve good data of the Earth surface for cloudless sky, as clouds would interfere with the correct view of the land surface. For this reason, it was necessary to download a fair amount of data to select those intervals with better visibility as to avoid gaps in the visualization. The product that was selected offered averaged values for night time and day time Land Surface Temperature. These were chosen as to give a more representative view of common situations rather than to peak a particular day of observation. Finally, over 120 files were scrutinized to select 6 winter and 6 summer days and nights. From these, only the six summer nights are presented as they offer the clearest cases of different land surface temperature distribution. It is necessary to remark that all observations recorded by MODIS are time specific, this is, they correspond to actual measurements carried out at a specific time and, unlike common climatic datasets, they do not represent mean values from records of several years. The last step before the analysis was to process the data in GIS software. For this exercise GvSIG, Sextante and the Remote Sensing plug-in were used. The images were combined and temperatures were scaled so that instead of absolute values (i.e. 21 or 23ºC) they became relative values to a reference, which was, in this case, the lowest temperature in the region (i.e. +2º or +4 ºK). This allows easier comparison between regions, as the absolute temperature may vary among them. Finally a color code was applied in a range of 12K temperature scale.

The processed images (fig.4-17) will be used as basis for the analysis of the spatial distribution of UHI and its correlation with urban features such as density or land use. The six pictures depict the surface temperature for the average summer night in the fourth week of July 2004, except for Madrid and Berlin, for which the data was taken for the first week of June of the same year due to the better quality of the observations on that night. At a first glimpse, the contour of the main cities can be quickly identified as they stand out in the intense red that represents the warmest areas. The surface temperature decreases gradually when moving from urban centres outwards. Typical suburban values are around 6K lower while the difference is greater for distant rural zones (about 8K cooler). The presence of geographic features such as large water bodies or mountain chains explains deeper differences, up to 12K, observed in maps. The correlation between urbanization and surface temperature is therefore verified by the satellite images. However, a more precise analysis is required to explore which factors inject a greater influence in warming cities up.

4.2.1.3 Population density and Urban Heat Island

In a second stage, land use and density patterns of the six cities were superimposed to the heat maps in order to find congruencies between UHI and spatial aspects. To facilitate visual analysis, the data were plotted as cross sections: from the city centre to 50km away, in two different directions for each case. Density values were obtained from the 2001 Census by the European Environment Agency and Eurostat[42]. For temperature, Modis images were used. The study of density to temperature profiles reveals (fig.4-18) a

38 aqua.nasa.gov [last accessed 1/11/2012]
39 modis.gsfc.nasa.gov/about [last accessed 1/11/2012]
40 hmodis.gsfc.nasa.gov/data/dataprod/dataproducts.php?MOD_NUMBER=11 [last visited 1/11/2012]
41 lpdaac.usgs.gov/tools/modis_reprojection_tool [last accessed 1/11/2012]
42 www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2 [last accessed 31/11/2012]

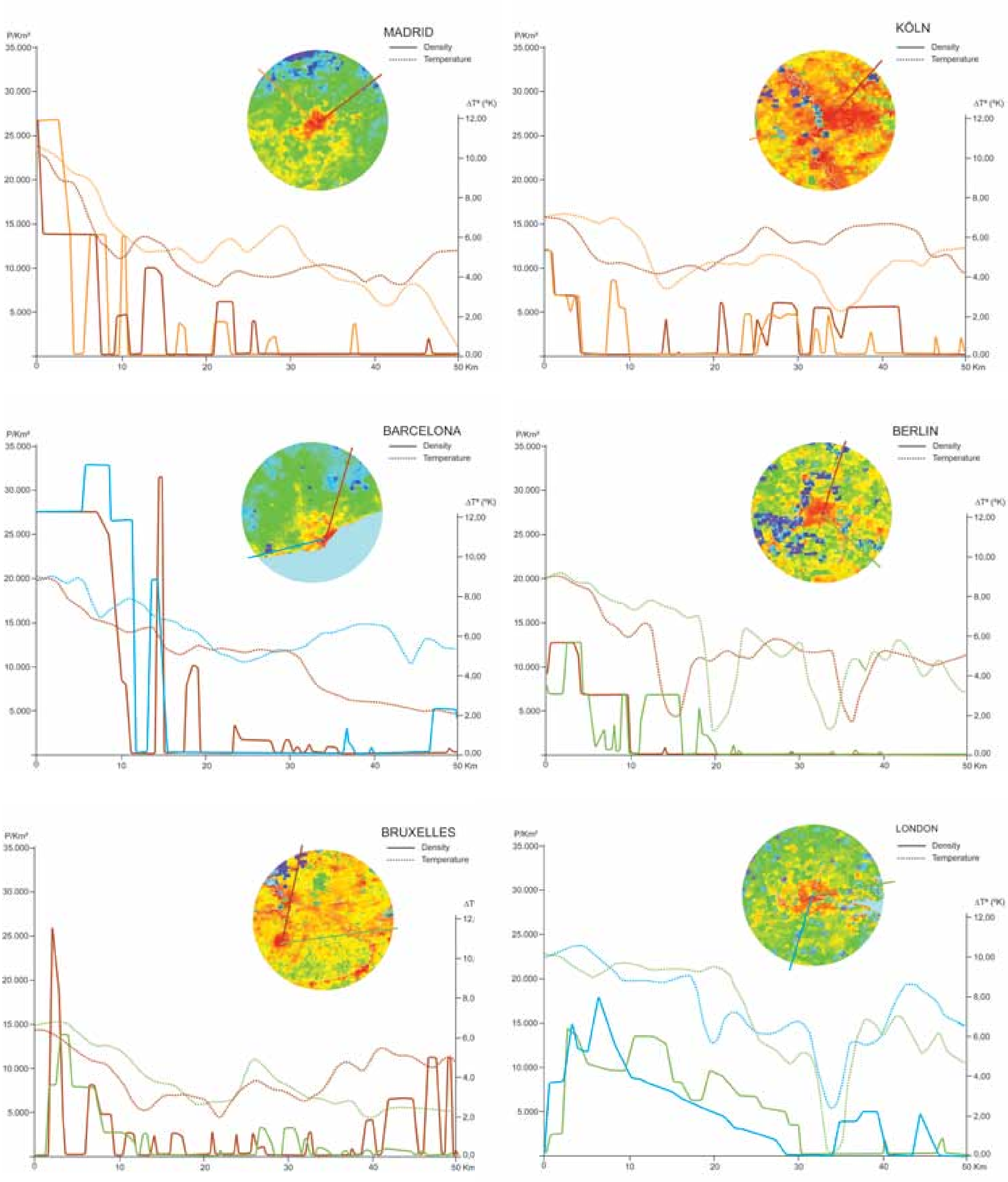

Fig.4-18 UHI against density in six European capitals

certain correspondence although the results are not totally conclusive. Temperature does decrease when density values go down, especially in Madrid and London, where the two profiles (density and temperature) run almost in parallel in some sections.

In London, residential density peaks are not at the city centre but in at the inner suburban ring, at a distance ranging from 4 to 7 km from Saint Paul's cathedral (symbolic centre and core of the City, the financial district and oldest part of London). In those areas, density is around 15.000 persons per square kilometre and temperature is up to 10K higher than the reference value. The two cross sections run Eastwards and Southwards respectively, in both cases the decrease of population density is relatively steady, although slightly more irregular towards the East, where industrial estates and residential suburbs are intertwined. It decreases dramatically at 30Km from the centre, at the metropolitan Green Belt that had been officially incorporated by the Greater London Plan in 1944[43]. The territory is predominantly rural beyond the Green Belt, with a couple identifiable satellite towns in the Southern axis. The effect of the old the Green Belt can be also detected in the thermal profile of both sections. Between kilometres 30 and 40, surface temperature dips, reaching minimum peaks within the study area to recover typical suburban values, around 6K above the reference temperature, beyond the Green Belt.

Despite the intense suburbanization of the last decade, Madrid still represents a more compact model. Residential density reaches 25.000p/km² in the inner five kilometres and is kept near 15.000p/km² in the first conurbation, which extends up to 15 km from the centre. Satellite towns are scattered between kilometres 20 and 30. Beyond that distance, rural landscape dominates. Cross sections were taken for the Northeast and Northwest axis, as they are aligned with two important corridors that connect the Spanish capital with Galicia (a North-Atlantic shipping node) and Catalonia (Mediterranean port and gate to central Europe) regions. These axes have absorbed a substantial part of the urban growth in the last decades. Land surface temperature analysis shows warmer temperatures in the central districts, which are 5K higher than in the suburban ring. The different performance between the suburban fringe belt and the countryside is better illustrated by the Northeast axis. The thermal gradient in this case barely reaches 2K. Sharper fluctuations on the Northwest extreme are explained by Navacerrada Mountains, which elevates 1,000 meters above sea level.

Barcelona is frequently quoted as a model of compact city[44]. It concentrates a great proportion of population on its central districts, whose peak density is slightly above 30.000p/km². The proximity to the sea and a hilly topography determine the location of urban settlements, either along the coastal line or at the inner valleys. The two sections selected for the analysis portray these two scenarios. The first axis goes along the coast from Barcelona to the Southwest, while the other axis connects Barcelona and Montseny, a mountain range to the North of the city, crossing industrial and satellite towns in Vallés and Granollers. Thermal fluctuations are softer than in Madrid (about 2-3K between the centre and rural areas) due to the effect of the sea. The elevated topography from kilometre 30 and beyond yields a further 4K decrease in the Northern axis.

Berlin can be considered another compact example. It presents a clear star shape with eight lobes that project along the main transport corridors. Central densities are moderate, about 12.000p/km² in the inner ring and 7.000p/km² up to 15 km outwards. In outer areas, densities drop to minimum values, with the exception of the villages connected to the Berliner, which runs around the capital at an approximate distance of 20km. The sample sections run along the northern and south-eastern lobes. The former is within Barnim district, an sparsely populated region that contains large natural areas, a feature that also characterizes the southern axis, along the Dahme-Spreewald, a district that contains large woods and numerous lakes. The whole region is predominantly flat. Land surface temperature fluctuations are small. It barely drops 3-4K between Berlin's urban centre and surrounding countryside. Greater fluctuations can be only explained by the presence of large water bodies such as lakes or reservoirs.

Brussels and Cologne, or rather Flanders and Rhine-Rurh regions, present similar patterns, both in their urban structure and in the spatial distribution of the thermal observations. They are located at the core of the most important economic belt of Europe, which extends from Southeast England to the Mediterranean French coast and has been dubbed as the "blue banana"[45]. They have taken advantage of their centrality in the European single market to boost new economic activities. Population sprawls over the whole region as it can be observed from density graphs. Scattered towns with densities beyond 2.000p/km² give little space for rural patches. In the case of Rhine-Rurh region, the urban continuum forms an extensive blanket with multiple centres (Cologne has one million inhabitants and Dortmund, Essen, Duisburg and Düsseldorf are above half million each). Whereas in Belgium, Brussels has a stronger hierarchy, possibly reinforced by its position as capital of the EU, and Antwerp and Genk play a complementary yet essential role as industrial and communications nodes of this densely populated triangle. In both cases, land surface temperature measures present rather flat profiles. However, the typical fluctuations in the densest areas (i.e. Brussels) and the presence of medium sized cities can still be inferred by reading the thermal profiles.

43 Foley, 1963

44 Urban Task Force, 1999

45 Hall and Pain,2006 p.10

4.2.1.4 Land Cover and Urban Heat Island

The previous analysis has shown the correlation between density and the intensity of the UHI. However, density alone is an ambiguous indicator of urban form due to the different spatial manifestations that are possible for the same values. Furthermore, underlying factors hidden behind residential density may have an stronger influence on urban warming. In the case of land surface UHI, surface properties and land coverage are especially relevant, as these are critical factors to determine surface temperature. The next stage of the analysis looked into different types of surface coverage to see how dominant features could influence land surface temperature. Data of land cover was obtained from GMES

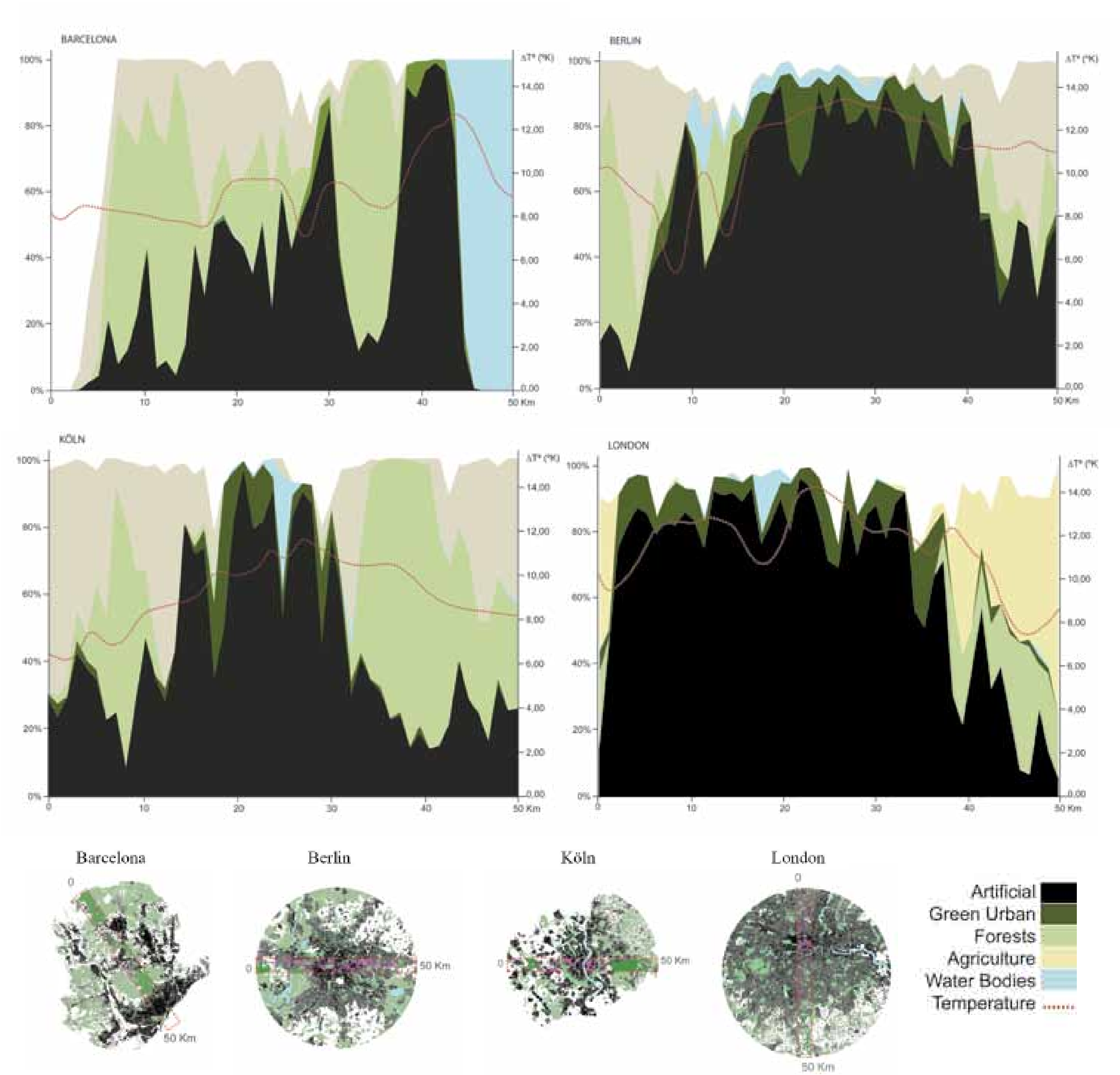

Fig.4-19 UHI against land use in four European capitals

Urban Atlas[46] and processed in GvSIG, Open Office and MS Excel. Due to the morphological similarities of Barcelona and Cologne respect to Madrid and Brussels respectively, only the two former are presented, together with London and Berlin in this second stage. A 50 by 2 km band was delimited for each metropolitan area. Unlike the previous sections, the selection is not radial but diametrical, this is, it starts from one extreme of the metropolitan area and it finishes at the opposite border, after crossing through the city centre. The second methodological difference lays in the use of bands instead of linear sections. In order to match the resolution of land cover cartography and MODIS imagery, the band is divided into 500x500m cells. For each cell, the area of each land cover type is measured and stored. The whole band has then 100 rows and 4 columns of data, which allows to produce longitudinal sections with the corresponding land cover break down. Although the Urban Atlas database contains 21 different land use types, they were grouped into five categories, while land without designated use was left blank:

- **Artificial land** includes buildings, industry and transport networks (roads, railway tracks, etc...)
- **Green urban**, stands for parks, gardens and open field sport facilities (football, cricket pitches..)
- **Forests**
- **Agricultural land** represents farmland, pasture and semi-natural features
- **Water bodies** include all accountable presence of water; rivers, lakes, channels or open sea

Interestingly, the plotted graphs (figs. 4-19) not only revealed insights about the environmental behaviour of the cities but they also highlighted broader urban aspects, such as the provision of green areas (significantly low in central Barcelona) or the extension and intensity of the urbanized territory. Considering the urban core as the areas where artificial land accounts for over 80% of the total, Barcelona urban area barely extends over 10 km inland, whereas London, in contrast, spills in a 30km diameter. In the four cases, land surface temperature follows variations in artificial cover proportion. In Berlin, variations up to 6K in less than 5Km are highlighted. In those areas the degree of urbanization also shifted dramatically from 40% to 90%. In London, the river Thames can be read in the graph as a thermal depression at the central city, as well as the boundary with the green belt, which appears as a marked decrease around kilometre 38. In Barcelona, the uneven terrain and the presence of the sea may influence thermal values. However, both the city and Vallés valley, a satellite "technoburb", can be clearly identified from the graphs as pushing temperature 4K and 2K upwards respectively. Finally, Cologne presents no dramatic fluctuations along its thermal profile. Although the most highly urbanized area concentrates in the central 15km, the whole territory is splattered with settlements of moderate density, which may prevent sharp differentiations.

4.2.2 Urban Climate: Learning outcomes

The interconnection between urban form, climate and energy has been explored in the previous sections. A causal relationship between the attributes of the city and a potential increase in the temperature of the urban fabric, especially during cloudless summer nights, has been found. Eventually, this may result in urban buildings demanding a further energy intake to satisfy comfort standards indoors. This effect is more relevant in warmer climates and it can be intensified if global warming forecasts are realized. The following remarks could be added to synthesize the previous observations:

- The occurrence of urban heat island is a major factor in the shaping of the mesoclimate of metropolitan regions. The direct extrapolation of weather station climatic values may result inaccurate as design data for urban locations, particularly in large dense cities.

- The elements that determine the intensity of the UHI can be divided in two broader categories: city attributes and weather conditions. Certain urban characteristics enhance the formation of distinctive microclimates in cities but, according to observations and satellite imagery, the intensity of the UHI will be ultimately determined by weather conditions. The lack of wind and clouds, warm daytime temperature and strong vertical solar radiation are favourable conditions to induce sharp thermal variations between the city and rural areas. Figure 4-14 showed how the transition from a sunny to an overcast day reduced the intensity of nocturnal heat island from 10K to a negligible value.

- The evaluation of the consequences of UHI in energy consumption is determined by location and the climatic sensitivity of buildings. Assuming typical construction and typologies, a rough estimation was done to compare the effects in two different climates. Results suggest that UHI may not have a substantial effect in cool-temperate regions, where the hot season is both mild and short. However, they also confirm an increased overheating risk for mild and warm regions (such as Barcelona, Rome or Athens). In those locations the increase of the cooling load could be very significant. Energy loads are not only intended to quantify the potential demand but they also indicate underlying aspects of life quality. If the cooling load is large, it often indicates overheating, which may have negative consequences upon vulnerable population (poor, elderly...)

- The connection between urban morphology and temperature is well established. Oke had already identified

46 The Urban Atlas is providing pan-European comparable land use and land cover data for Large Urban Zones with more than 100.000 inhabitants as defined by the Urban Audit. The GIS data can be downloaded together with a map for each urban area covered and a report with the metadata.
www.eea.europa.eu/data-and-maps/data/urban-atlas

density and urban canyon as related to heat island intensity in the seventies[47]. The broad range of tools that is currently available allows new insights to those early findings. The combination of satellites, sensors and telecommunication technologies provide data of land surface temperature for almost any given location at anytime of the year. The comparison of surface temperature with spatial characteristics, such as density or land cover, confirms the correspondence between urban form and UHI. However, caution is needed as the satellite data refers to surface temperature, which may vary respect air temperature and it is strongly influenced by variables, such as albedo or emissivity, that are material dependant. Another finding was the effect of mitigating elements within the city fabric (parks, lakes, rivers...). They have a potential to generate cool spots whose extended effect are quickly reduced with distance as they are barely noticeable beyond few blocks. This would advise about a regular distribution of parks in warm cities, so that the joint effect could have a global repercussion upon urban temperature.

4.3. Buildings Energy and Urban Form

4.3.1. Variations in performance

A survey on the energy cost in office buildings was retrieved by Baker and Steemers to illustrate the wide range of values in energy performance that could be found for to same building type[48] . It proved, they argued, the great scope for improvement that could be achieved by conscious and well informed design. The identification of variables that, being within designers' control, affected that divergent performance was crucial. A wealth of literature and studies has been produced in the last decades on the physical processes that shape energy consumption of buildings. They encompassed different climates, types and approaches. A comprehensive list would include highlights such as Olgyay[49] and Koenigsberger[50] (tropical climates), Givoni[51] (architecture and urban design), Yannas[52] (housing), Szokolay[53] (a general handbook on building's environmental science) and Baker and Steemers[54] (non domestic buildings) among many others. They have provided a solid knowledge base on how buildings work and how they can be better designed to improve their environmental performance. However, despite all the computational and analytical power at our disposal,

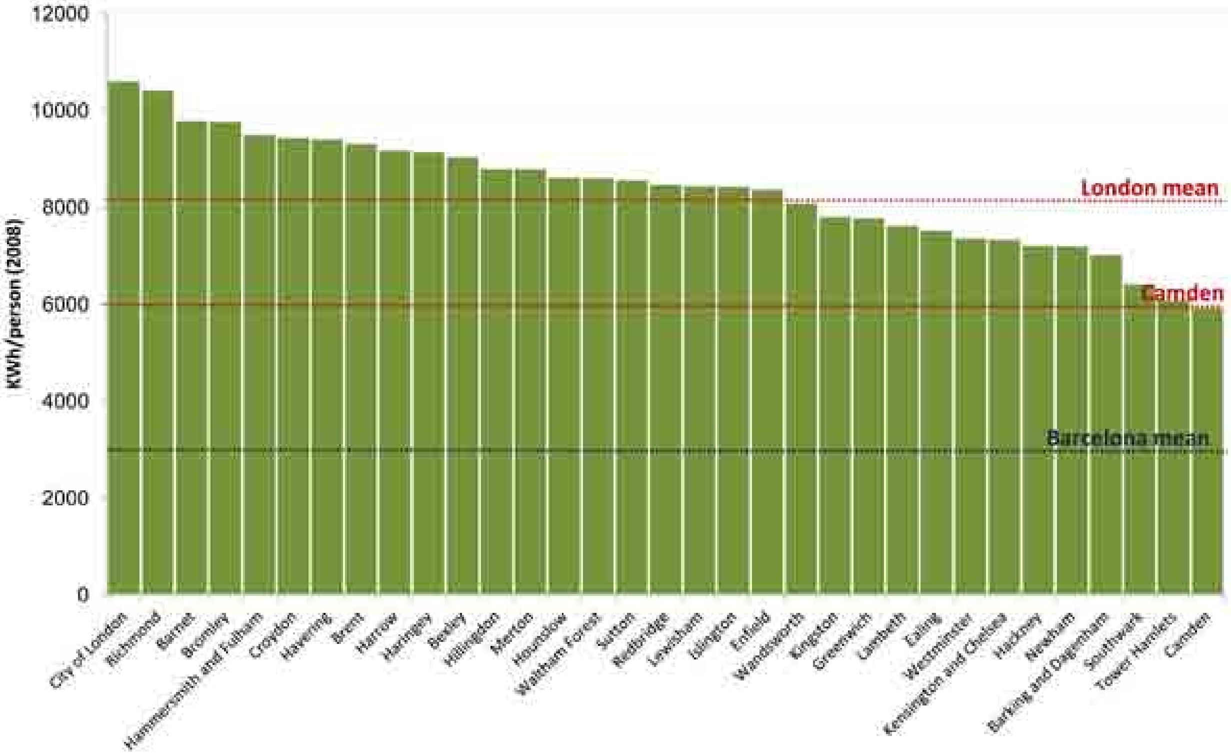

Fig.4-20 Final domestic energy use in London boroughs in 2008 (data from GLA,2010 Leggi 2008 Database). Barcelona council mean final domestic energy use in 2008 (data from Ajuntament de Barcelona, statistics office) The data has been contrasted for the years 2004 to 2009 and the distribution pattern was consistent with this figure.

47 Oke, 1987

48 Baker and Steemers, 2000
49 Olgyay, 1963
50 Koenigsberger et al 1973
51 Givoni, 1998
52 Yannas, 1994
53 Szokolay, 2004
54 Baker and Steemers, 2000

there is a high degree of uncertainty in these estimations. This is derived from users' interaction and the complexity of other external factors such as climatic conditions or the urban setting. It was estimated that the behaviour of the occupants can induce a variation in energy consumption of a factor of two, which can only partially explain the wider discrepancies that were found in empirical studies (variations up to 20x in similar building types)[55].

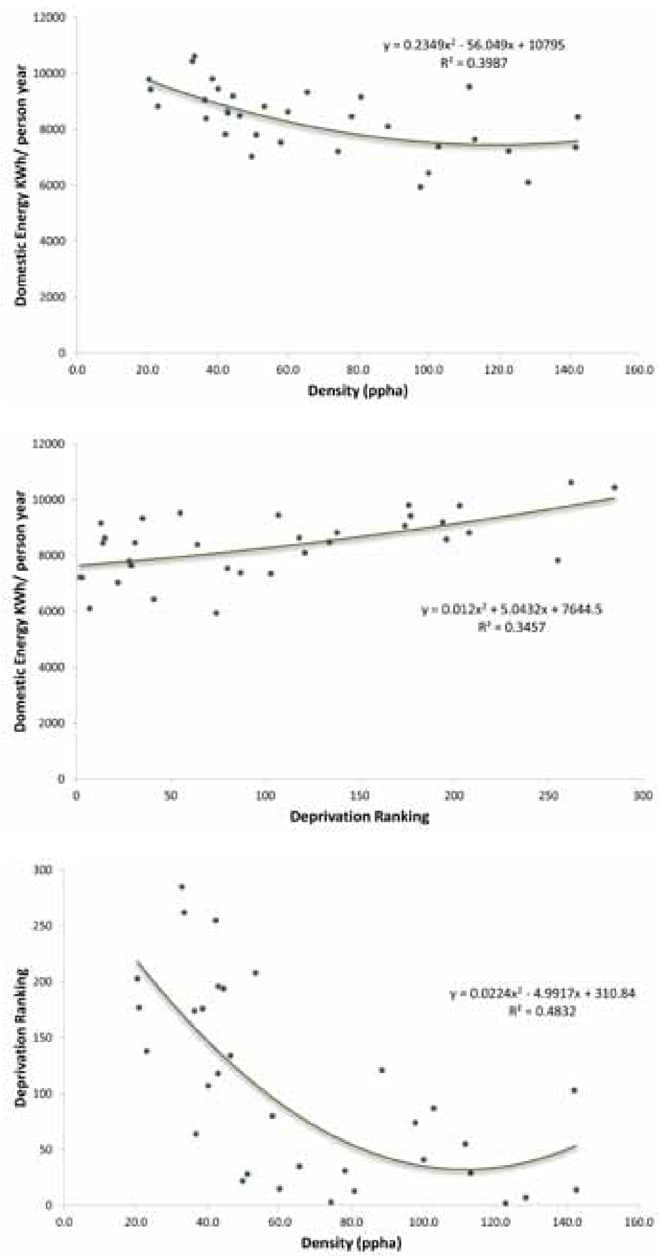

Fig.4-21 Correlation between deprivation (left) density (centre) and domestic energy consumption in London boroughs (data from GLA) Correlation between density and deprivation (right)

55 Rati et al, 2005

If the issue is extrapolated to the urban scale, a similar observation can be drawn. The divergence in performance between near locations will also appear. A similar reasoning could then be applied to suggest that there is potential to design cities in a more efficient way and yet avoid taking a too energy deterministic approach. The examination of London borough's domestic energy consumption (fig. 4-20) reveals variations up to 30% above and below the mean value of the metropolitan area (GLA). Domestic energy accounts for about one third of the total demand in London and, unlike other sectors such as transport or industry, energy is consumed in buildings and largely influenced by their physical attributes. If empirical data confirms this broad variations, there is an implied connection between location in the city and energy consumption or, in other words, it proves that citizens that live in certain boroughs tend consume more energy than residents of other areas. There is a myriad of factors that are relevant in shaping demand patterns: household income and composition, lifestyle, home size, age and state of conservation to name just a few. Regression analysis was carried out to find possible correlations with employment rates, deprivation, average salary and tenure type but results were inconclusive. Only a weak correlation with deprivation level (r^2=0.34) was found but it was not sufficient to explain substantial digressions to both sides of the trend (Camden, Hammersmith, Kingston or Haringey).

The influence of spatial characteristic was initially explored by analyzing borough densities. Although connections were only dimly signalled, the dispersal distribution (fig. 4-21) seemed to suggest certain patterns that could be better investigated at a closer scale. The interdependence between density and deprivation was examined in a third test. It revealed an even stronger correlation (r^2=0.48) than in the previous analysis. This could provide grounds for different hypothesis: wealthier households tend to cluster in specific boroughs and may prefer larger homes with their private gardens. It results in low densities and higher energy consumption. Conversely, low income classes tend to live in smaller flats, with fewer appliances (smaller TVs, fewer gadgets...) and less space to heat up. It translates in higher densities and less average energy consumption per person.

Any of the abovementioned theories could probably be refuted in the light of any thorough research as they came out of sheer speculation. However, variations in domestic energy consumption above 50% between Camden and Hammersmith or Chelsea and Barnet clearly indicate a waste of resources and a great scope for energy savings at urban scale. Moreover, these boroughs share similar lifestyles, wealth and provide good opportunities. Camden has, for instance, many of the most preferred residential locations of London. Some quick estimates give an idea on the potential savings without necessarily compromising lifestyles. If all London boroughs performed as the average value for the Great London

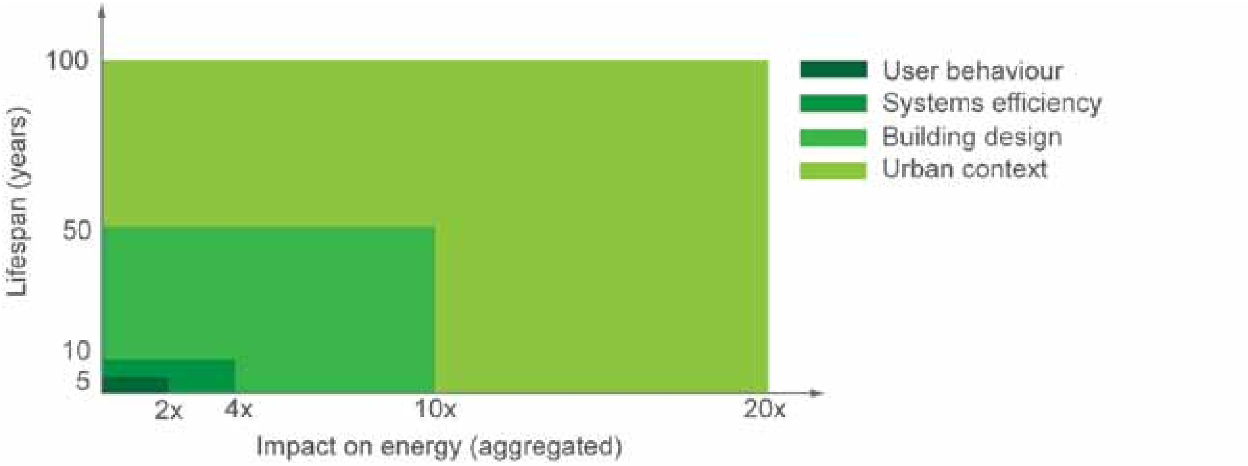

Fig.4-22 Variables affecting energy consumption. In the X axis variation factors related to each variable (after Baker & Steemers, 2000). In the Y axis potential lifespan for behavioral changes, systems, building and the urban context

Authority (GLA) or below, the overall domestic energy for the whole metropolis could be reduced in 5%, which is around 4TWh every year (4 billion KWh). In economic terms, it would represent about 240 million Pounds[56] (300 million Euros) in savings for private households. Taking a more ambitious approach, if all boroughs were to match Camden energy ratio, the overall savings would rise up to 30%, which means 19TWh for the GLA and over one billion Pounds (1,400 million Euros). All this could be done, a priori, without the need for Spartan changes in people's lifestyles as it was proven in Camden borough, which has the sixth highest gross salary within the GLA and it is a lively and comfortable place to live[57]. It might well be the case that all that energy and expenditure is redundant, unnecessary and therefore dispensable. Therefore, the issue could be reformulated as to question the convenience, affordability and even the social equity that results from the unequal distribution of energy resources.

How can then other London boroughs imitate Camden successful performance? Is that a matter of good governance and effective development policies? or rather a result of favourable spatial settings? The answer to these questions requires a sharp discernment of the factors that determine energy performance at both building and urban scale. Camden is densely populated (9,800 persons per Km^2)[58] but it is not as dense as Islington or Chelsea (14,000 persons per Km^2). It ranks third in jobs density in the GLA, after the City and Westminster, so that it gets a good mixture of land uses and easy access to facilities (90% of the population lives within 400m of a food store[59]) but these factors are unlikely to affect domestic energy a direct way. The council has been active in developing planning policies and guidance for refurbishment and new dwellings[60] and it has set the ambitious target of achieving zero carbon for all new dwellings from 2016. However, sustainable development policies have not been specific to Camden and even if they were to determine standards for new buildings, the effects would start be noticed in the medium or long term.

Notwithstanding the importance of socioeconomic variables, a limited direct effect in the shaping of domestic energy demand can be assumed so as to focus on spatial and morphological attributes, which are in the scope of this thesis. Rati et al[61]had grouped the variables that determine energy performance in buildings (apart from climate) in four categories: urban context, building design, systems efficiency and users behavior. These variables were then assigned variation factors according to Baker and Steemers estimations[62] in order to point out how the divergence grows in geometric progression with the aggregation of the various scales. The broad range that was found in surveys is attributed and weighted in relation to each overlapping layer (fig. 4-22**.** From these deductions, building design accounts for about variations up to 2.5x factor, and the urban context would be responsible for differences up to 2x. The combined influence on variations of building design and urban context is then 5x (2.5*2). The high influence of design aspects deserves even more attention when the lifespan and the resistance to change, of the intervening variables is taken into account. Because even if behavioural patterns were inducing a high

56 Assuming an average cost of energy : 6pence/KWh (www.energysavingtrust.org.uk) [last accessed 11.11.2012)300

57 The author has lived in Camden for three years, so the statement comes from personal observation

58 GLA datastore

59 Williams, 2000

60 Policy CS13 - Tackling climate change through promoting higher environmental standards

Policy DP22 - Promoting sustainable design and construction

Camden Sustainability Task Force, 2007

London Borough of Camden, 2011

61 Rati et al,2005

62 Baker & Steemers, 2000. Although they considered non-domestic buildings in their analysis, the logic behind the figures can be applied to understand the important role of each scale-variable

energy consumption, it could be handled and modified in a short period of time, just by adapting or engaging certain habits. In contrast, if buildings' poor performance has to do with their urban settings, any improvement may result unfeasible in the short term, since the complexity and cost of transforming the existing urban fabric makes it an sluggish and arduous process. Urban developments are made to last for a minimum of 50 years[63] and, despite rare exceptions such as the Pruitt-Igoe[64], they tend to persist much longer. Even though buildings may have been replaced in the last century, the urban structure of plots and paths of many historic European centres has remained unaltered for hundreds of years. Recent urban expansions are unlikely to gain the social affection that enabled the conservation of the old cities. However, their medium term endurance is assured due to multiple ownership, which prevents unilateral decisions, and unaffordable land value, which prevents general compulsory purchase orders. Because many generations will have to cope with the consequences of poorly designed cities, it is paramount that every aspect of urban interventions is considered thoroughly. The energy performance of resulting structures is, besides, a meaningful indicator of urban quality since excessive values may evidence the inadequacy of the spatial arrangement of streets and buildings in that part of the city.

Back to the initial question, it is possible to find out a bit more about what has made a difference in Camden by looking into some statistics that characterize local buildings. Interestingly, Camden has one of the lowest ratios of detached and semidetached dwellings in London (fig.4-23). This characteristic is shared by other boroughs at the top of the domestic energy efficiency, such as Tower Hamlets and Southwark. The ratio of detached, terrace and flat accommodation is an important factor to explain the divergent performance among London boroughs. It is well established that detached houses tend to consume more energy as a result of their high envelope exposure and heat losses[65]. Flat accommodation is certainly not as appealing as garden living for Londoners, but it has been proved a more energy efficient building type under current construction standards. From this perspective, planning should aim to turn around the large proportion of detached housing by encouraging a progressive replacement of low density developments by housing blocks and tower flats. It would arguable improve the ability of the city to minimize energy demand from buildings but it would certainly make Londoners more unhappy.

Statistical correlations provide hints and help to work out hypothesis but they are not self-explanatory by definition. If other borough level building statistics available such as façade orientation, glazing ratio or obstruction..., were available then further hypothesis could be elaborated and tested to identify the relative merit of the different building attributes. As this is not the case at the moment, urban buildings' performance needs to be investigated analytically, this is by discerning the various factors and the extend to which they determine energy flows.

	DOM ENERGY RANKING	FLATS %	TERRACE %	DETACHED/SEMIDETACHED %	OTHER %	DENSITY ppha
Camden	1	47%	9%	5%	39%	98
Tower Hamlets	2	76%	13%	3%	8%	128
Southwark	3	60%	18%	8%	14%	100
Bromley	30	20%	22%	49%	9%	20
Barnet	31	28%	18%	42%	11%	38
Richmond	32	25%	28%	33%	14%	33
LONDON (avg)		25%	33%	26%	16%	50

Fig.4-23 Housing typology break down for the three most and least energy intensive boroughs (excluding the City) in terms of domestic energy (data: UK Census 2001)

63 EHE 08

64 Mentioned previously, it is an emblematic housing project in Saint Louis-USA that was demolished only sixteen years after completion due to the numerous problems. For many, it symbolized the failure of modern planning

65 Yannas, 1994, Urban Task Force 1999

4.3.2. Energy Use

Nationwide energy reports are elaborated regularly by national agencies to monitor the country's needs, policies and their dependence on external supply. These factors are critical for the national development and the economy, as an increase on fuel costs could trigger inflation in almost every sector and, eventually, compromise progress. Intuitively, one could tend to think in productive activities, such as transportation or industrial manufacturing, as the ones that require the highest demand of energy. Nonetheless, in many European countries[66] the energy consumed in buildings outweighs both transport and industry. Moreover, in some cases (Germany, Estonia, Latvia, Hungary, or Poland in 2009, United Kingdom in 2010) domestic energy alone has taken the largest share in the national demand. In the United Kingdom, space heating accounted for 26% of the global consumption of the country, 19% was required for heating up domestic buildings, 5% for commercial and office buildings and 2% for factories and industrial facilities (fig.4-24). No other category has had such a big impact as space heating and, at the same time, is present in three of the four main sectors (domestic, industry and services). Therefore any hypothetical improvement in heating strategies would have a multiplying effect at large scale. Looking more specifically into domestic uses, space heating accounts for almost half of the average household energy demand, closely followed by lighting and appliances (35%) with lower shares for hot water (15%) and cooking (2-3%). Interestingly, the two largest demands in residential buildings (heat and light) are directly connected with form and design.

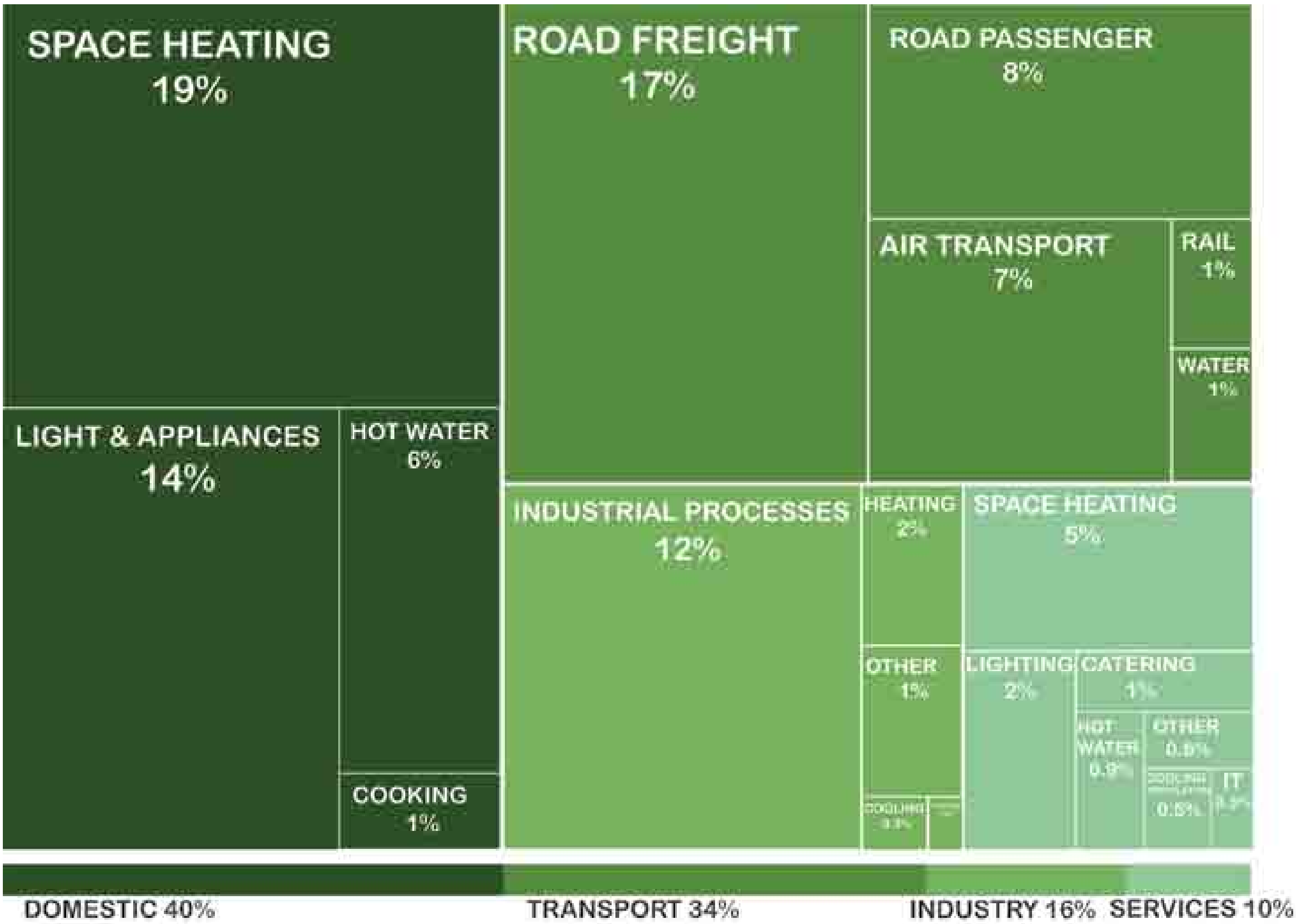

Fig.4-24 Energy breakdown by end use and sector in UK, 2010 (estimates derived from UK Statistics Authority)

66 Within EU: Denmark, Germany*, Estonia*, France, Italy, Latvia*, Lithuania, Hungary*, Netherlands, Austria, Poland*, Romania and United Kingdom (Eurostat,2009)

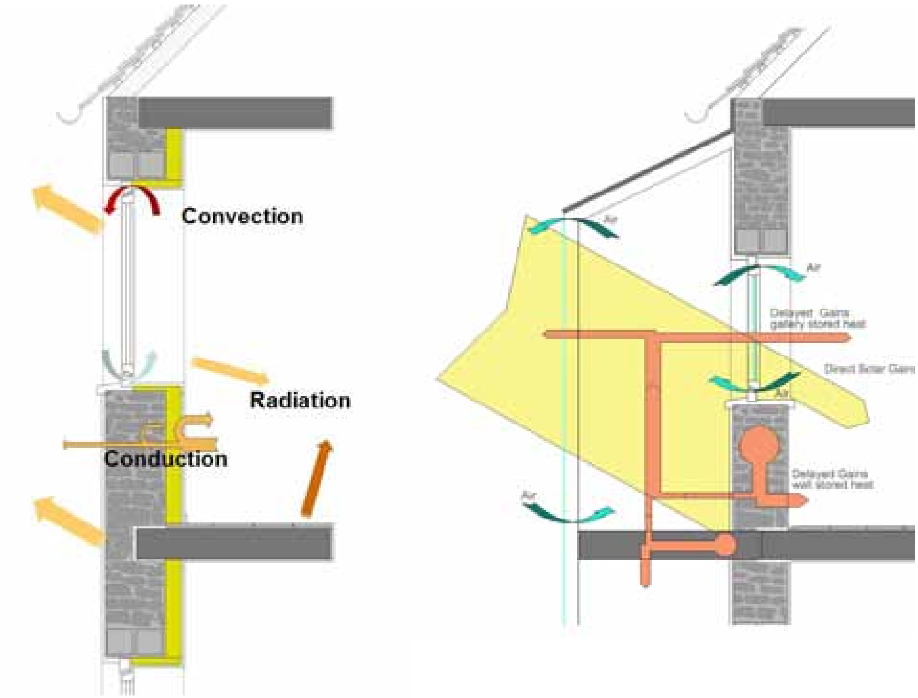

Fig.4-25 Heat flows through the building envelope in a simple wall and a glazed balcony (Rodríguez Álvarez, 2008)

4.3.3. Fundamentals of Space Heating

Additional heating may be periodically required in internal spaces which are regularly occupied or where activities require specific thermal conditions. The primary target of building design is to provide comfortable environments for humans, thus space heating is a mechanism to complement the shelter provided by the building's envelope when this is insufficient to offset external temperatures. In order to determine when and to what degree shall this happen, it is necessary to enquire about users' preferences (their comfort standards) and the climatic context (how cold and how often). Both aspects may be indeed interrelated as the adaptation to the context influences preferred conditions.

The study of thermal comfort is a long established discipline that has greatly evolved in the last decades. Early standards were defined as a rather deterministic imposition, based on laboratory experiments that informed uniformly narrow thermal bands. These were mainly intended as design temperatures to size mechanical systems in a worst case scenario approach. In 1953, Olgyay introduced the bioclimatic chart, a graphic tool to visualize the combined effects of architectural design, environmental conditions and human comfort[67]. It facilitated the integration of comfort parameters in architectural design decisions and unveiled certain flexibility in the environmental requirements. The narrow comfort zones were gradually replaced by adaptive theories that, after Humphreys (1978) and Auliciems (1981), were based on the correlation between thermal tolerance, external conditions and users' choices. These studies found that, on the one hand, the temperature that users feel as neutral depends on their previous short-to-medium term experience, this is, the prevailing weather conditions they have experienced in the last weeks or last month. On the other hand, they discovered that the presence of adaptive opportunities, described as the possibility of users to react against uncomfortable conditions, by removing a sweater, opening a window or moving a desk, expands their tolerance and, subsequently, their comfort zone.

External thermal temperature marks the baseline that buildings need to rise as to provide high quality environments. The distance between comfort and outdoor value has to be balanced, preferably by means of good design and material specification. Badly designed or poorly constructed buildings may rise, in absence of additional heating, external temperatures by a couple degrees, which is by far insufficient in most parts of Europe for long periods of the year. In contrast, optimized design, good solar access and generous insulation can deliver a rise in internal temperature up to 15K above outdoors, as reported by monitoring studies in free running buildings[68]. The increase of internal temperature without conventional heating can be generated by the action of two mains sources: solar radiation and internal heat gains. Solar radiation is captured through glazed openings and stored in the fabric of the building. The heat is then gradually released to the internal environment in the form of longwave radiation.

67 Olgyay, 1963

68 Conçeiçao et al, 2009

Internal gains are produced unintentionally by the occupants as a result of their mere presence and the tasks undertaken indoors. The human body is itself a heat source. Likewise, lights, appliances or electronic equipment release heat as result of the inherent inefficiency of energy transformation processes. When these internal heat sources are in operation, the indoor temperature tends to increase. Since buildings are still coupled to their external environment, the difference in temperature triggers a process to restore the balance inside-outside. Consequently, heat tends to escape from the warmer (internal) to the cooler (external) environment. This process is known as heat loss[69] and it is closely regulated by the building's envelope, which is the ultimately filter for the outgoing heat flow. A leaky, permeable and largely exposed envelope will enhance heat losses. The heat flow would find little constrains to escape, either through the wall, by conduction, or through cracks in joints and openings, by convection (fig. 4-25). The heat gains that had been achieved due to solar and internal action cannot be effectively transformed in actual increase of internal temperature unless heat losses are controlled. The real increase will result from the balance between the intensity of gains and losses. If the losses are far greater than the gains, the internal temperature would tend to follow external values. Conversely, if the losses are controlled and become less intense that the gains, then the internal temperature may gently rise as long as internal heat sources are in operation. Once they cease, the temperature will start a decreasing pace whose slope depends on heat loss ratio of that space. To maintain the room within comfort zone the heat supply must be balanced with the heat losses. The greater the losses the larger the heat input needs to be. Incidental and solar gains may be too little for a number of reasons: cloudy days, overshadowing by adjacent buildings, low external temperatures, low occupation or badly insulated buildings are factors that undermine the total amount or the practical value of the gains, which may not compensate the heat loss rate. This is a common scenario that leads internal temperature to drop and calls for conventional heating to prevent thermal conditions to fall below comfort.

4.3.4. Space Cooling

European cities extend over a broad territory and are therefore exposed to a range of different climates, from Subarctic in Finland and Norway to warm Mediterranean in Italy or Spain. However, the most populated areas are located in Oceanic and Continental zones. It means that they have mild to cold winters and cool summers. In all European countries, conventional heating is used for certain periods of the year, taking an overall 70% of the energy consumed by European households[70]. In Mediterranean countries, such as Spain or Greece, although the heating needs are lower, due to their mild winters, the need for cooling rises due to warmer temperature and strong radiation levels. Cooling has been often disregarded in energy and building policies across Europe, the main reason was the temperate climate and the minimal impact on national accounts. However, the increased affordability of domestic cooling systems and the current construction trends, moving towards high airtightness and insulation levels are boosting a new demand in areas where the use of air conditioning should be unnecessary. Field surveys have revealed cases of overheating in London contemporary flats for both intermediate and warm seasons[71]. Compact and small units, over insulated envelopes, abounding electronic appliances and inadequate ventilation have turned the scale in favour of the internal heat gains to such a degree that the space becomes overheated.

The axiomatic interpretation of energy efficiency as the minimization of heat losses and maximization of gains may further intensify cooling loads in many building types. In domestic environments, the ability to deal with overheating problems is relatively ample, as the user has a greater flexibility to adapt, either by operating windows, choosing a cooler place to stay or removing some clothes. In contrast, non domestic buildings are more liable to cause discomfort by overheating. They are typically densely occupied, normally during daytime and their activities require high lighting levels, technical equipment and the inability to move a workstation around the space. It all results in very narrow adaptive capacity which almost inevitably shoots up the demand for air conditioning. The flexibility in an office environment is partly determined by work related codes but a great deal can be done in terms of design to avoid overheating and improve the adaptive capacity of the occupants. Lighting gains can, for instance, be reduced if daylight is generously provided while avoiding direct solar radiation. A sound design of the openings should consider the effects of glare at the working plane, especially on computer screens, to avoid the haphazard use of blinds that prevent not only sun patches but also useful daylight. Internal gains tend to be underestimated in offices and commercial buildings. High occupancy ratios produce heat gains that may rise temperature to unbearable levels. In addition, occupants' breathing and transpiration compromise air quality. The provision of openings that allow fresh air to circulate effectively around the space could help to dissipate excess heat and to maintain indoor air quality. However, operable windows are rather not the rule in contemporary office buildings. Noise, pollution and safety issues have dissuaded designers, who relied on mechanical systems to provide fresh air and refrigeration in internal environments. Global warming forecasts and the poor efficiency of electricity generation stress the importance of buildings' capacity to dissipate unwanted heat.

69 Yannas, 1994
70 BPIE, 2011 p.10
71 Garg et al, 2010

4.3.5. Lighting

According to the data illustrated in figure 4-24, artificial lighting accounted for around 20% of the energy spent in buildings in UK in 2010. With a tendency towards passive heating and reduced heat losses, it is likely that the proportion of energy dedicated to lighting will increase in relation with other uses. Unlike heating or cooling, the total removal of artificial lighting is unfeasible without drastic lifestyle changes. There is, nonetheless, a great scope for achieving substantial savings in light consumption. The research in electric lamp technology seems to have reached an important landmark with the generalization of LED lamps. They consume around 10-20% of the electricity that incandescent lamps need for the same quantity of light, while having a much longer lifespan.[72] Potential savings are not restricted to technical solutions alone. Design can greatly improve the luminous efficiency of domestic and especially non domestic buildings. Daylight quality can vary substantially for different window positions and dimensions. Conventional side openings have a limited efficacy to light deep spaces properly. A long established rule of thumb suggests that any point beyond a distance from the window that is twice the window height will be poorly lit. The area comprised within these parameters is typically referred to as the **passive zone**[73]. The capacity of the building to deliver a passive performance is normally restricted to this narrow band, which is close enough to daylight, solar and ventilation sources. It could be assumed, when designing or evaluating a building, that any space beyond the passive zone will rely, by definition, on mechanical systems to provide visual and thermal comfort.

In typical working scenarios, sunlight is to be avoided, as it increases the risk of glare and overheating. In domestic environments, however, spells of sun may be valuable amenities, especially in gloomy climates where sunny days are scarce. For other functions, such as schools, halls or transport stations direct this is contentious. Sunlight can be either detrimental or beneficial for the spatial quality. It rather depends on the specific brief and design intentions. Anyhow, when calculating lighting for task performance, direct sunlight is normally excluded as, apart from its potential problems, it is highly dynamic and directional. Then, the provision of daylight is basically dependant on the sky or, more specifically, on the ability of the building to capture the illuminance from the sky and to distribute it uniformly to the internal spaces. There are three main paths that daylight can follow to reach a working plane:

- The most efficient route, is the direct visual connection with a patch of sky. Those spaces with a direct sky view will benefit from greater daylight levels than those at the same distance from the window without this view. This is referred to as the "**Sky Component**" (SC)[74] and it can be estimated by different methods, some of them in form of graphic diagrams or protractors that became common design tools in UK around the ninety eighties[75].
- Daylight can also reach the working plane after being reflected by adjacent objects, typically buildings. In this case, the amount of light depends not only on the sky conditions but also on the properties of the reflecting surface. A clear wall may reflect a greater proportion of the light it receives compared to a darker element. This is called the **Externally Reflected Component** (ERC) and it can be generated by single or multiple reflections on buildings, ground, walls or any other external element.
- Finally, any spot that does not receive any light directly from an external opening may still get some daylight by reflection on internal surfaces. This is called the **Internally Reflected Component** (IRC) and it is strongly affected by room finishing and layout.

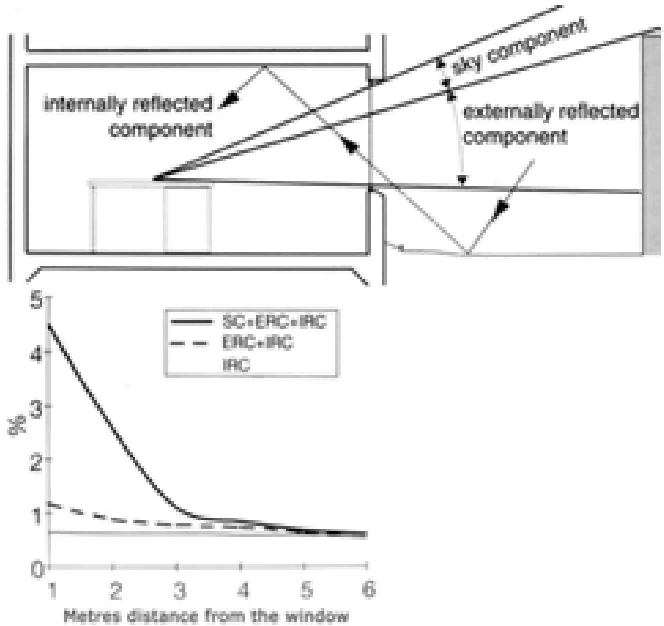

Fig.4-26 Three components of daylight factor (Baker,2010)

To realize potential lighting energy savings, daylight has to displace artificial lights for as long as possible and in as many areas as possible. In a typical open plan office, some workstations may be sufficiently lit whereas others, normally at a greater distance from windows, remain rather dark and call for artificial lighting. Centrally controlled systems that do not differentiate this subtleness will turn all the lights regardless space-specific needs. A careful system design should allow users to adapt lighting levels to their own needs thus allowing energy savings to be delivered. Potential

72 Szokolay, 2008 p.171
73 Baker and Steemers, 2000
74 Littlefair, 2011
75 Szokolay, 2008 p.156

daylight savings can be estimated by comparing frequency graphs of sky illuminance against the amount of light required by indoor activities and the proportion of daylight that effectively penetrate inside. Sky conditions are extremely variable and, in some climates, highly unpredictable[76]. For this reason it is preferable to gather statistics about the frequency of occurrence of illuminance bands. The ratio of daylight which is allowed into the internal space is known as Daylight Factor and it depends on building characteristics such as shape, orientation or windows but it is independent of the external conditions as it just reflects the percentage of light that reaches the indoor space. Illuminance values for typical tasks are compiled in codes and regulations[77], which prescribe recommended parameters for different space types.

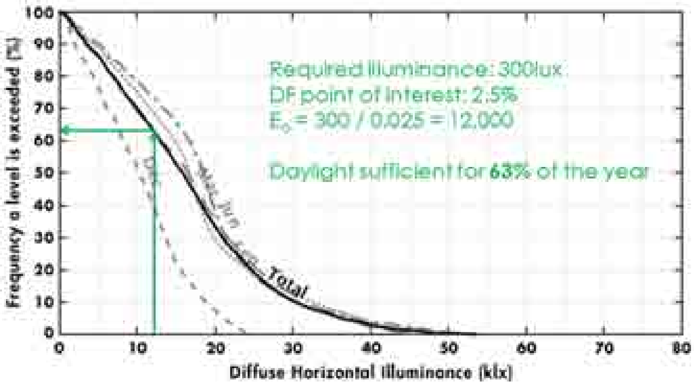

Fig.4-27 Cumulative frequency illuminance graph (source:educate-sustainability.eu)

4.3.6 Relations between aspects of urban form and the energy performance of buildings

4.3.6.1. The influence of the urban context

Early energy studies focused on the environmental analysis up to the building scale while the urban scale and the interaction between buildings was relatively ignored. Building regulations introduced measures to improve buildings' envelope by means of statutory insulation levels in the early eighties. It had a strong and immediate effect on the behaviour of new constructions for the energy demand was lowered due to the reduced heat loss. However, as various empirical researches pointed out, [78] the configuration of the urban fabric could prevent those buildings from getting the benefits of solar access, thus undermining potential savings. In a study of the energy performance of urban housing blocks in A Coruña, Northwest Spain, the limitations imposed by the urban fabric were further illustrated by the comparison of two buildings of a similar type[79]. One building was part of a post-war development. Its urban layout was composed by linear blocks and wide streets to maximize solar access and allow ventilation. The other building was at the historic city centre. The medieval street configuration was rather tortuous and had a narrow canyon, which enhanced overshadowing, especially at the lower floors. The thermodynamic analysis of these two cases showed the potential increase of internal temperature, without conventional heating, after environmental retrofit was carried out (fig.4-28). In the first building, the post-war development, the implemented measures delivered satisfactory results as internal conditions reached comfort levels for the whole studied period. In contrast, in the second case, the internal temperature barely increased by 4-5 degrees and it remained below the comfort zone. The construction characteristics of the two buildings cannot fully explain this different performance. They have similar values in terms of insulation and heat losses and, although they differ in depth and the size of openings, the differences at building scale do not explain the inability of the second case to achieve as good performance as the first one. A plausible hypothesis is that the urban fabric has prevented the building to deliver the energy savings' full potential. Therefore, individual performance was determined, to a great extent, by the urban configuration. Low energy buildings cannot be conceived as detached from their context as the surrounding environment will influence their level of achievement. This idea can be exemplified by some of the most notorious schemes that claimed sustainable merits in the last decades. BedZed in London, Masdar city in Dubai, or Dongtan in Shanghai went beyond building design to create their own urban context. Every parameter could be optimized to achieve the highest possible performance. These projects "deliberately eschew their urban context" to create "total designs" in self-contained enclaves[80].

4.3.6.2. New versus existing

In practice those models are difficult to generalize in European cities. Both Asia and the Middle East have experienced an important urbanization boom that has transformed former rural areas into new vast megalopolis. The large amount of available land allowed for integral schemes and cities designed from scratch. The urbanization of Europe is in a much more mature stage. There is barely any tract of natural landscape that can be urbanized without a strong opposition from environmental or social groups. Moreover, planning policies aim for the concentration of construction activities within the existing urban domain to enhance compact growth and mitigate the impact of sprawl. The scope for grand projects that neglect the existing city are hardly justifiable in Europe. Some recent examples were circumscribed to property speculation and they have delivered unfortunate

76 For instance in coastal areas of North Spain or South East England where moderate winds cause sky conditions change from cloudy to intermediate and sunny in a short time period

77 CIBSE Guide A

78 For instance, Rickaby 1987

79 Rodriguez Alvarez, 2008

80 Carmona, 2012

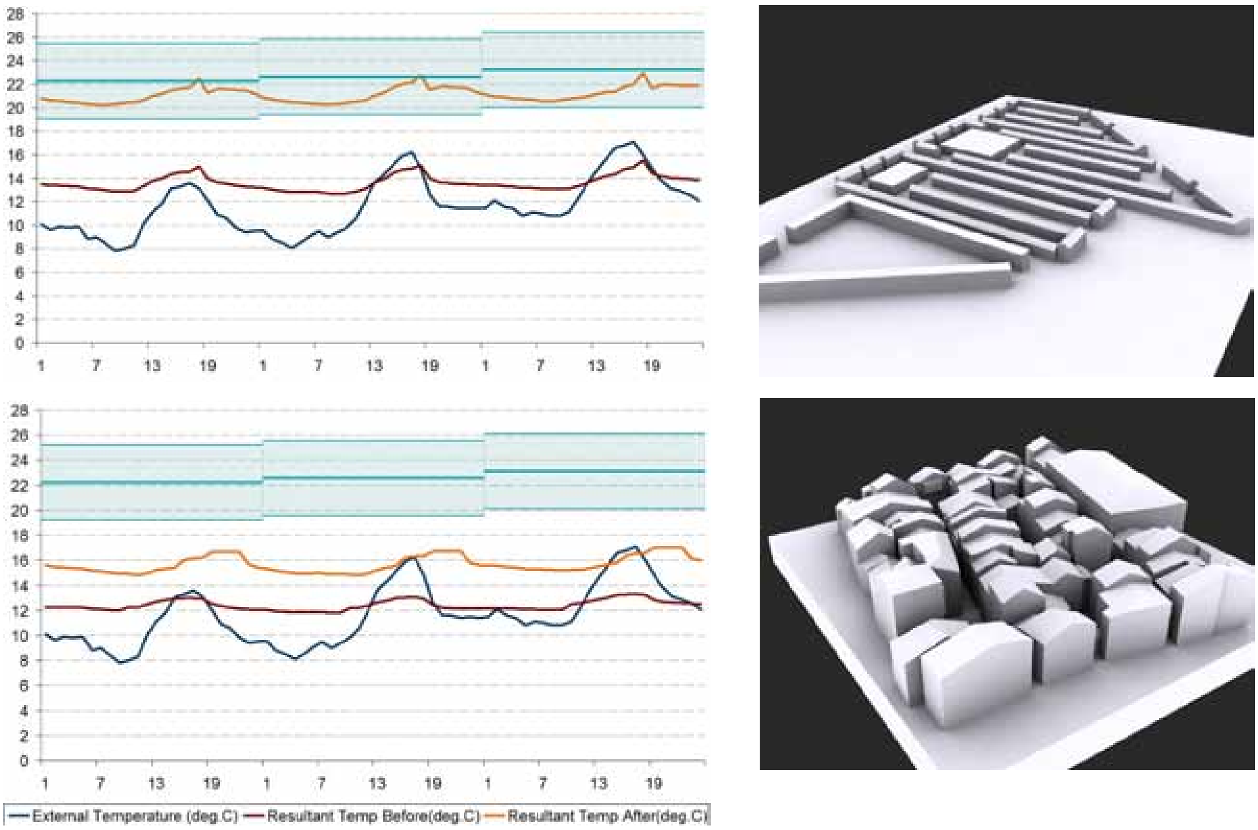

Fig.4-28 Estimated free running performance of housing units before and after retrofitting measures, typical winter week in A Coruña, Spain. The building at the top is located in a post war development, that allows good solar access and it maintains internal temperature within comfort standards. The building at the bottom is situated on a dense area with narrow streets and limited solar exposure. It illustrates how the urban context limits the environmental behavior of buildings (Rodríguez Álvarez, 2008)

results. Rural landscapes were fileld with dreadful skeletons of unfinished constructions that were caught by the economic crisis of 2008[81]. Inner city projects can benefit from the existing infrastructure and urban services, vacant lots are reclaimed and a new population is attracted to revitalize the local community. Both the new and the existing can coexist in symbiotic relationship. The new interventions will alter the previous conditions in different levels, from social to microclimatic. Conversely, existing structures will determine the potential achievements and they will establish certain requirements for the design of future developments. Low energy projects that engage infill regeneration face greater challenges and limitations but they can deliver greater improvements if the overall context is considered.

The analysis of the urban setting is, therefore, critical to estimate the environmental performance of urban buildings. The question is whether the urban variables that most influence buildings' performance can be effectively identified. Figure 4-29 represents a matrix that illustrates connections between genuinely urban characteristics and attributes at building level. The former were divided in four categories: users, systems, building design and urban context. The understanding of the consequences derived from the large scale context (macro or mesoscale) towards the individual unit (microscale) helps to clarify the potential efficiency of urban areas without the need for painstaking analysis of every individual element.

4.3.6.3. Climatic Conditions

Climate is a primary definer of energy demand. If weather conditions were always comfortable, internal spaces could be completely coupled to the external environment and the only reasons for enclosure would respond to safety and privacy. As this is hardly the case in European climates for most of the year, buildings have to provide shelter and insulation from external conditions. Hawkes described two possible approaches to building design as response to climate: exclusive and selective[82]. Selective mode refers to the use of ambient energy sources in the indoor environment, whereas the exclusive mode implies a deliberate isolation

81 See for instance www.lavanguardia.com/vida/20121013/54353010538/pinchazo-burbuja-inmobiliaria-urbanizaciones-inacabadas.html [last accessed 22.11.2012] or http://news.bbc.co.uk/1/hi/business/7584097.stm [last accessed 22.11.2012]

82 Hawkes, 1996

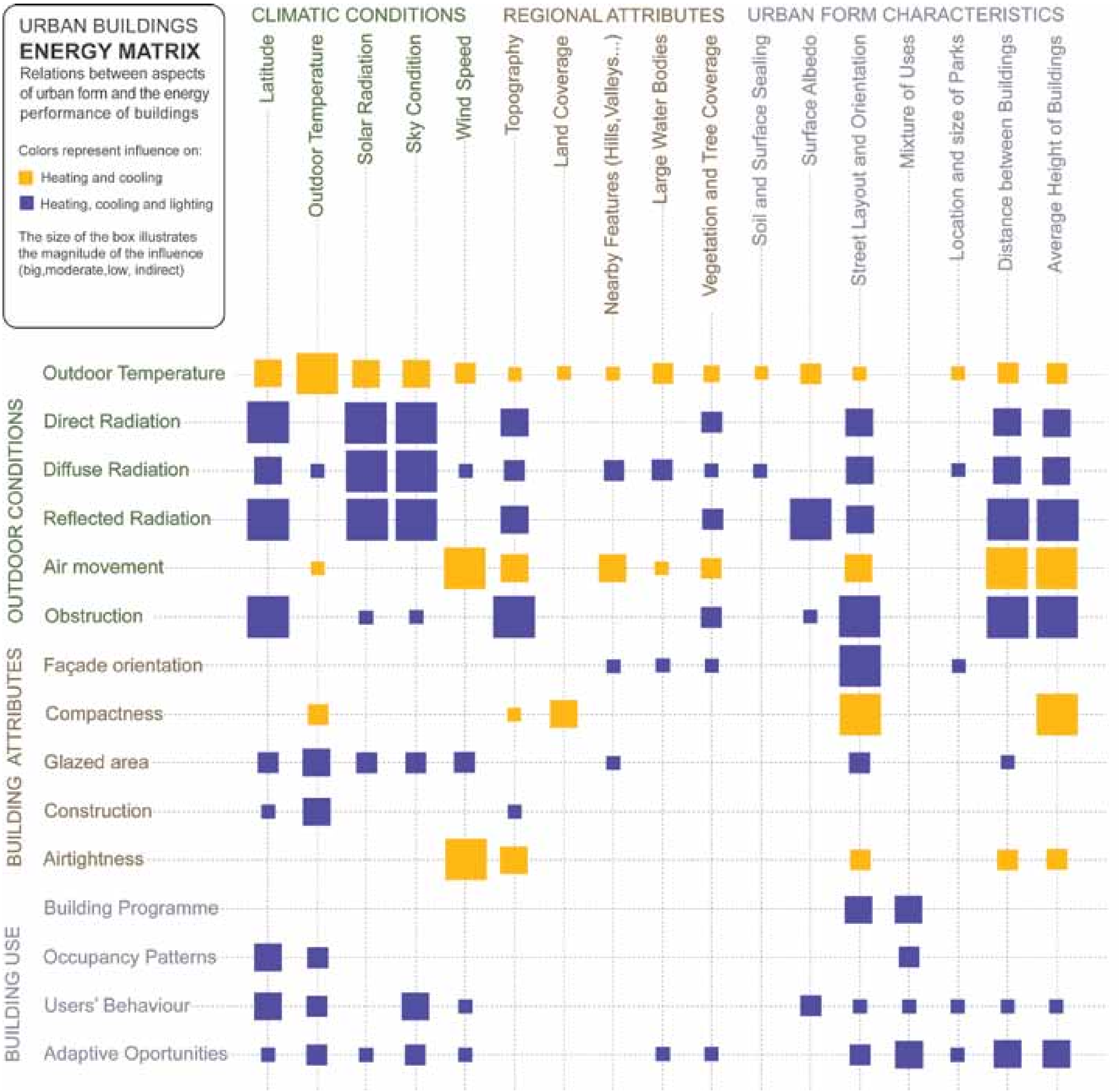

Fig.4-29 Urban Building Energy Matrix. Relations between aspects of urban form and the energy performance of buildings

from outdoors to rely internal comfort solely in technical and mechanical means. For any of these approaches, outdoor conditions are always determined by the geographic location, mesoclimate and the potential modifications exerted by regional and urban specific characteristics.

The **latitude** of a given location determines its distance and inclination in relation with the sun. As solar energy drives terrestrial climate, the relative position to the sun is of great importance. In northern latitudes, sunrays have to traverse a longer distance through atmospheric layers which reduces the intensity of incoming radiation due to the filtering effect of the gasses. Once the rays reach a surface at ground level, the low inclination angle also reduces the potential absorption and the subsequent warming up of the material. As a result, northern climates tend to be cooler and present lower radiation levels than southern latitudes (obviously in the North hemisphere).

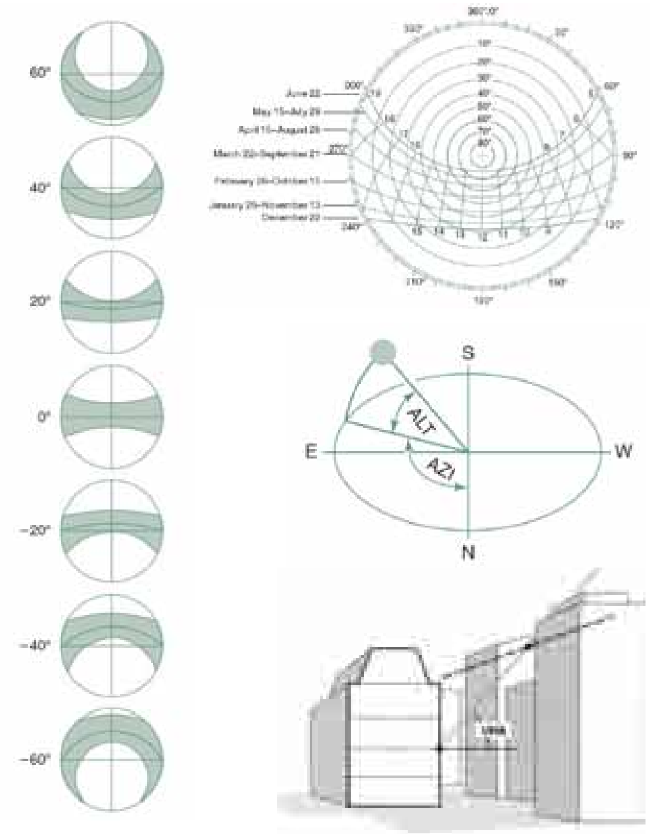

Fig.4-30 Latitude defines solar altitudes that influences minimum distance between buildings to avoid obstruction (Szokolay, 2008 Baker & Steemers, 2000)

The **sun path** for any given latitude can be traced by geometric procedures. It allows to know the position of the sun anytime in the year with great precision. There are two main coordinates to define solar position: altitude and azimuth. They are relative measures to an hypothetical observer that would be placed at the centre of the sky hemisphere[83]. This system of reference facilitates the understanding of solar dynamics in relation with specific locations. The altitude defines the vertical angle between the horizon and the sun position whereas the azimuth measures the horizontal deviation from the north. High latitudes have low solar altitudes, which increases the risk of overshadowing from the obstruction generated by adjacent buildings in dense urban areas. In the band between parallels 40º and 50ºN, the solar altitude at noon varies from around 20º in December to over 70º in June. The high summer sun also facilitates solar control by means of horizontal shading devices, which allows low angled winter rays while blocking more vertical direct radiation in warmer seasons.

Climatic zones shaped by solar energy and terrestrial forces have also influenced characteristic social values and traditions for each culture. Vernacular architecture and people's behaviour have evolved during centuries to adapt to the climate of each place. In warmer areas, dressing codes, traditional food, drinks and customs will differ from those in cooler areas as they have to assist to alleviate hot weather. Likewise, vernacular architecture has developed a location-specific language. The size of windows, the integration of shading devices, colours and materials have been evolved by the anonymous collective in a process of many centuries. Unlike the universal contemporary style, local Heritage has not been immune to the process of climatic mutation which may be translated in buildings being more sensitive or selective of external conditions.

Fig.4-31 Climatic adaptation in vernacular architecture (left, source: Behling, S. (2000) Solar Power: The Evolution of Solar Architecture) versus current international style (right)

4.3.6.4. Regional attributes

A city's climate is influenced by its geographical settings. Regional features modify ambient conditions and continentality affects seasonal extremes[84]. The topography may create microclimates or a distinct mesoclimate that affects the entire region. The presence of mountains, water bodies or forests alters the energy balance between terrain and atmosphere, creating irregular winds flows and radiation budgets. A south oriented hillside can received three times more radiation than a north oriented one[85], which is likely to create a strong thermal gradient and induce air movements. When a settlement is surrounded by hills and mountains, they create a depression that may obstruct winds altogether. In warm climates this is an added risk for overheating as ventilation of urban buildings becomes more difficult.

Forests, crop covers and vegetated surfaces exchange water and heat with their surroundings as a result of transpiration and photosynthesis. Large forests affect the water cycle as they intercept an important proportion of

83 Szokolay,2008 p.23

84 Grimmond, 2012

85 Oke, 1987 p.151

rainfall, which is stored in their leaves. The moisture is then returned trough evaporation from the wetted foliage or by transpiration via the stomata.[86] They eventually induce further climate modifications as wind flows are dragged and their speed is reduced by the tree canopy. Moreover, the air is cooler and the atmosphere gets humidified under the trees. These effects are mainly local and circumscribed to the boundaries of the forest. However, the cooler breeze may still be perceived in windward areas. A similar cooling effect may be originated and enhanced by the presence of water bodies such as rivers, lakes or oceans. The high thermal inertia of water softens temperature and the evaporation from its surface layer loads the atmosphere with humidity. In warm seasons, air temperature near rivers can be around 3-5K lower than a similar place without the refreshing effect of water. In winter periods, large water masses release the stored heat very slowly, so it remains warmer than the land thus creating thermal gradients, which are more pronounced during night time.

The intensity and distribution of urbanization in the region will also modify climate and, subsequently, building's behaviour. Urban heat island has been extensively documented and it was also discussed in detail in previous sections of this thesis. Apart from anthropogenic heat, urban activities also generate moisture (from combustion and refrigeration processes) and pollution, which reduce air quality while enhancing a greenhouse effect on the urban canopy layer. Polluted outdoor air may compromise ventilation and, consequently, the potential of urban buildings to maintain adequate air quality and to prevent overheating by natural means. The emission of dust and pollutants into the atmosphere contributes to a double alteration in the radiation budget. On the one hand incoming shortwave radiation is intercepted to a greater extent than in cleaner environments, which tends to reduce global temperature. But on the other side, carbon dioxide and aerosols also prevent radiation heat looses from the urban fabric to the sky, for which temperature around buildings in cities tend to be kept higher[87].

Urban areas can be compact and dense, (more population concentrated in a smaller area, e.g. Barcelona), compact rural (low density village, e.g. Toulouse region), densely sprawled (e.g. London) or rurally sprawled (e.g. Lille region). In the study of twenty six European metropolitan regions, the percentage of urban land use in ranged from 3-4% in Barcelona or Rome to 14% in London and Cologne with a maximum in Brussels (20%)[88]. The proportion of urban land cover gives an indication of building types. Although the connection is not straightforward and it has to be taken with caution, sprawled regions tend to have a greater proportion of suburban detached and semidetached housing units whereas compact areas have more flats and housing blocks. As single family houses have a larger exposure, they tend to lose more heat and require more conventional heating to counteract the losses. If there were a region-wide building compactness index, it is more likely that it would be greater is cities such as London or Brussels than in Barcelona or Frankfurt. The study of the metropolitan form is relevant to the anthropogenic modification of climatic conditions.

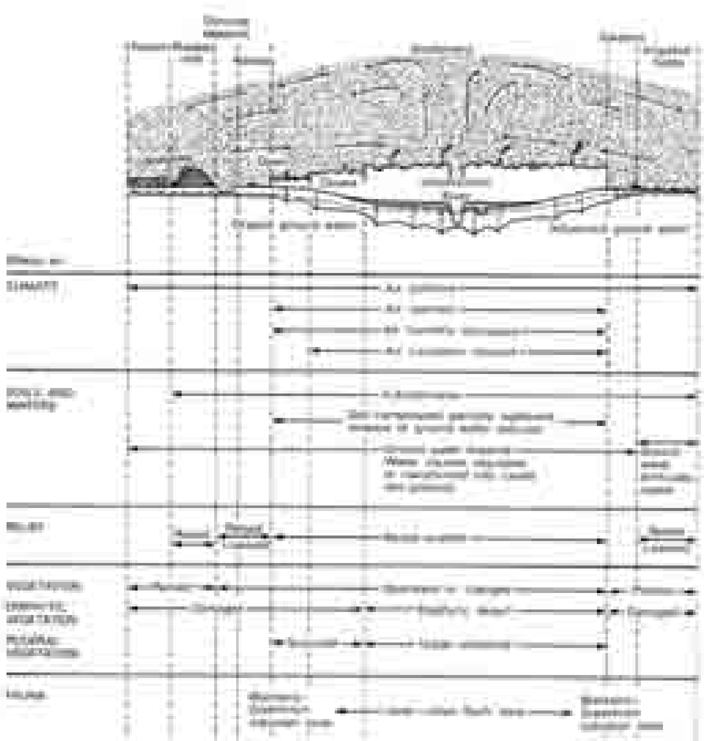

Fig.4-32 Environmental impacts of urban growth (Douglas, 1983)

4.3.6.5. Urban Form Characteristics

When an infill site is designated for refurbishment, the performance capacity of the new scheme is limited by the existing structures and the surroundings. Even if the site is completely cleared, the underlying urban texture will influence and limit the building's ability to perform to the full potential of current knowledge and technology. The building footprint is adapted to the existing street layout and orientation. In many cases the orientation of available plots is not ideal for passive performance or they are too deep, or too narrow or too irregular...design ingenuity can overcome part of these issues, but many aspects go beyond the architects reach as they have been set at urban level. Urban form influences the immediate outdoor conditions that the building has to balance. The fine grain formed by streets and plots will ultimately define whether and to which extent can a building respond to external conditions by means of passive design.

The most enduring element of European cities is perhaps

86 Ibid p.122
87 Douglas, 1983
88 The area comprised for the analysis was 225 million ha in every case.

the most decisive from an energy perspective. The use and the material attributes of urban buildings can change in a short term. Floor plants can be added or removed. A partial refurbishment can transform the building function. Walls and pavements can be painted or cleaned, which would change the albedo and the thermal properties of surfaces. However, the street configuration, although it may be altered to some extent, tends to remain stable for decades or even centuries. There are numerous examples of medieval layouts that have been preserved almost intact. Buildings may have been replaced by new ones but the street pattern remains the same. Many of the streets in central London can be clearly recognized in 17th century maps (e.g. Strand, Kingsway...). In Barcelona, the Gothic quarter has been densely developed on top of the medieval structure (although there have been partial demolitions in the 20th century) and buildings fill their narrow and deep plots between narrow and irregular streets. Empirical evidences and simulation studies such as those illustrated by figure 4-28 have shown the poorer performance of buildings with high obstruction in these historic dense areas.

4.3.7. Energy analysis of urban form. Early precedents

The influence of urban morphology in the energy consumption of buildings has been addressed by different studies, which tried to quantify it. In most cases the analysis focused on solar access and ventilation patterns, and the impact on heating and cooling loads. A pioneering study by **Knowles**[89] took a different approach. He aimed to develop a planning method to control urban growth so as to ensure good solar access in most buildings. He started analyzing historic settlements that were excavated in the rocks of Colorado and New Mexico, US to identify the interactions between those forms and solar dynamics. He found that buildings were placed inside the cave in such a way that the total energy falling on their walls and terraces was only 12% lower in winters respect to summer months, despite longer daytime hours and the higher intensity of summer sun. Moreover, the efficiency as solar collectors was actually higher in winter, due to the larger surface exposed to the sun. This was possible because the shape of the cave blocked a great part of radiation when solar rays were closer to the vertical plane in summer months, while it allowed most of the winter low sun angles. After these findings, Knowles elaborated some energy diagrams to compare the energy efficiency of simple formal arrangements of: linear, terraced and piled units[90]. From the analysis of the diagrams he confirmed the good performance of the primitive settlements and argued that those tribes were fully aware of sun dynamics and they had purposefully aligned their buildings to maximize solar access. From this idea, he then developed the concept of **solar envelope**, which

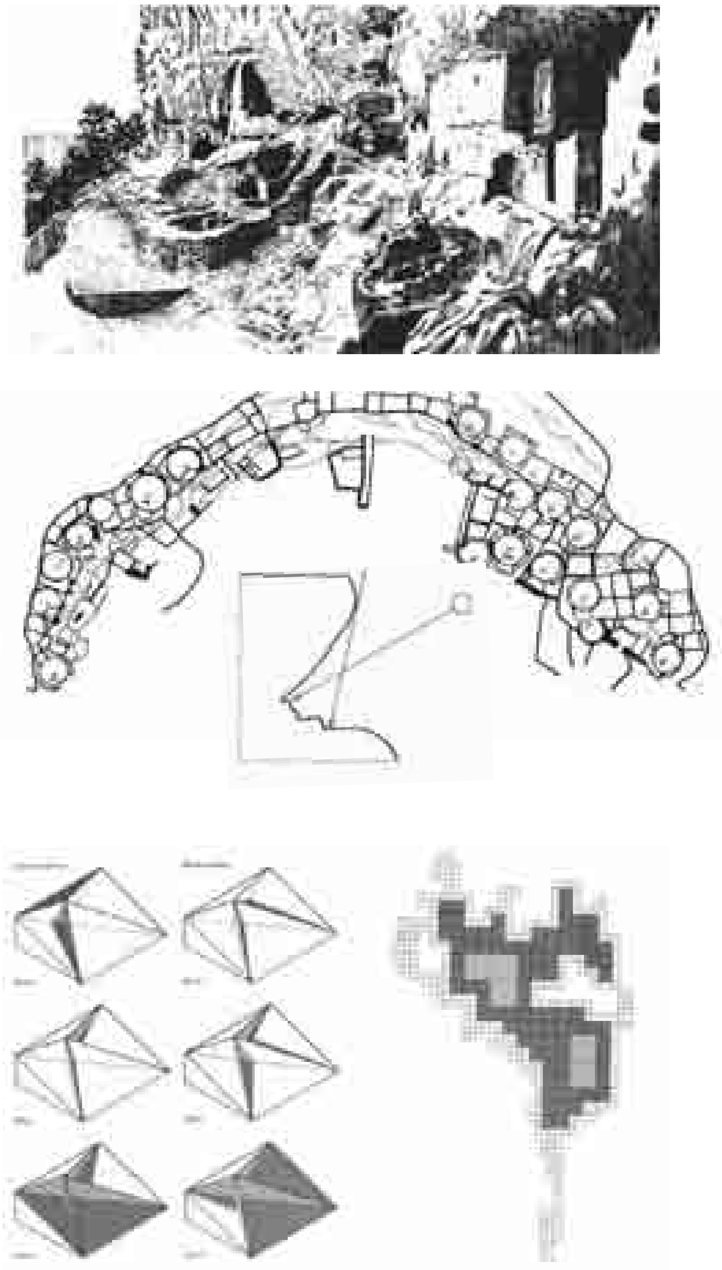

Fig.4-33 Primitive settlement (top) and solar envelope to organize the urban structure (bottom) according to Knowles' proposals (Knowles, 1974)

consists on a pyramidal shape that defines the "*maximum allowable volume that could be built without extending shadows beyond the square*"(its base, which represents the plot) "*during the critical insolation period of each day*"[91]. On this theory, a solar envelope would be defined for every grid cell of the urban structure. Topography and orientation would characterize the size of the grid, where each increment would represent a plot. Buildings would be laid over and confined within the boundaries of the solar envelope. To add

89 Knowles, 1974

90 Ibid, pp.32-33

91 Ibid, pp. 118-119

diversity, he proposed different organization levels, so that the original cells could be merged to create different sizes and shapes. Buildings in that urban system could be designed with predictable characteristics of insolation. He illustrated his point with some experiments where the aim was to make the energy falling in building surfaces equal in summer and winter periods. He defended the merits of this method as opposed to conventional urban planning, which lacks the necessary diversity and neglects the natural environment and, particularly, energy conservation issues.

4.3.8. Energy analysis of urban form .General guidelines

Later studies offered design guidelines for site layout, which included information on the critical spacing between buildings in relation to their height and the effect of orientation on heating and cooling. Yannas proposed a minimum distance between dwelling rows around four times the height of the obstruction for a flat site in Latitude 50-50º North to ensure a clear view of the sun in mid December (fig.4-34), which gives an obstruction angle around 16 º[92].He also analyzed the increase in space heating when main elevation could benefit from southern aspect. Using computer models and insulation levels from the building regulations of 1990, he estimated an energy cost of up to 15% when the main elevation was oriented westwards. Similar recommendations were given in the handbook that was delivered by an European Commission Research Project that aimed to produce "comprehensive design guidance on urban layout to ensure good access to solar gain, daylighting and passive cooling"[93] For the same latitude, they recommended a maximum obstruction angle of 20⁰ and, when possible, a southern orientation, within the range of 30⁰ deviation from the south axis.

A different approach was taken by a research conducted by LSE and EIFER[94]. They selected twenty sets from five real cities to define dominant urban characteristics of those urban forms. The aim of the study was to establish unambiguous correlations between macro-morphological variables, such as building density, surface to volume ratio, building height and surface coverage of buildings, with heat energy loads. If connections were consistent, this information could be used to inform development policies. In a first stage of the project, the heat load of each sample was modelled in iterative sequences to evaluate the weight of morphological parameters in the final energy demand. Other factors, such as climate or building construction were kept constant. The importance of urban form was confirmed at this early stage, since variations up to a factor of seven were identified for the different samples. Preliminary conclusions seemed to suggest that building height was the most powerful indicator

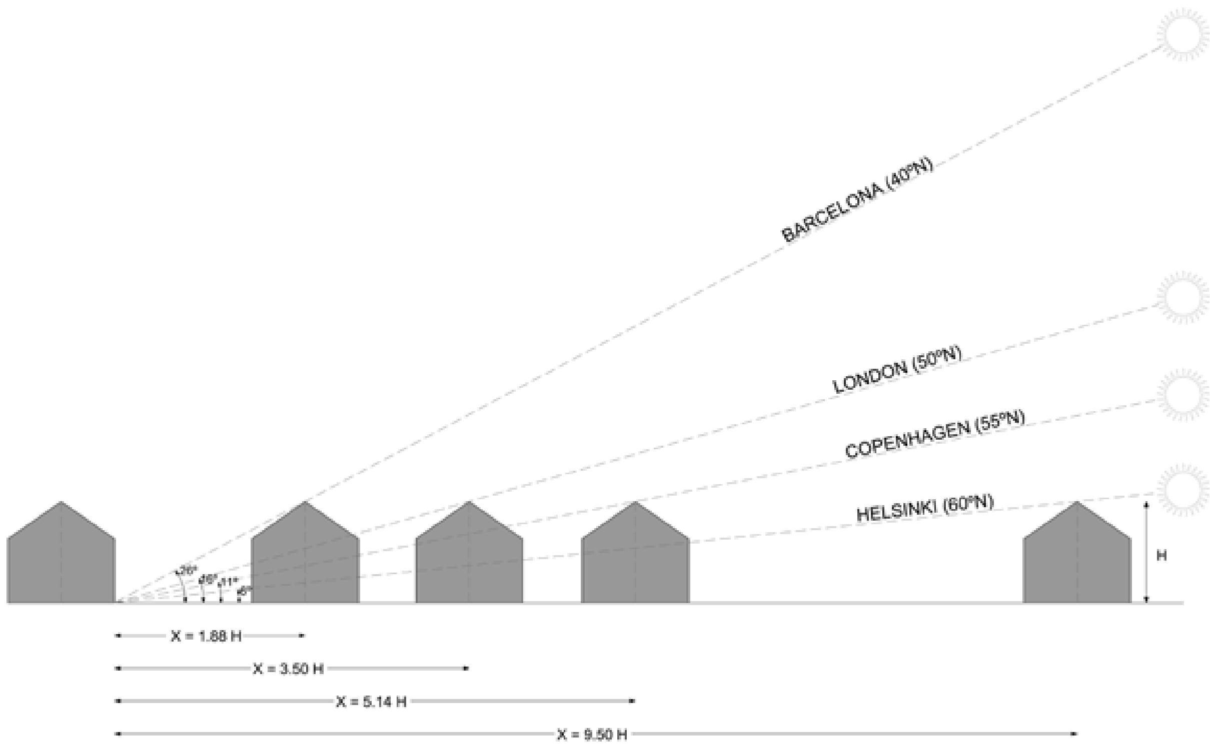

Fig.4-34 Minimum spacing required for view of the sun at noon in mid-December at different latitudes (after Yannas, 1994)

92 Yannas, 1994 p.54

93 Littlefair et al, 2000

94 LSE Cities, EIFER, 2010

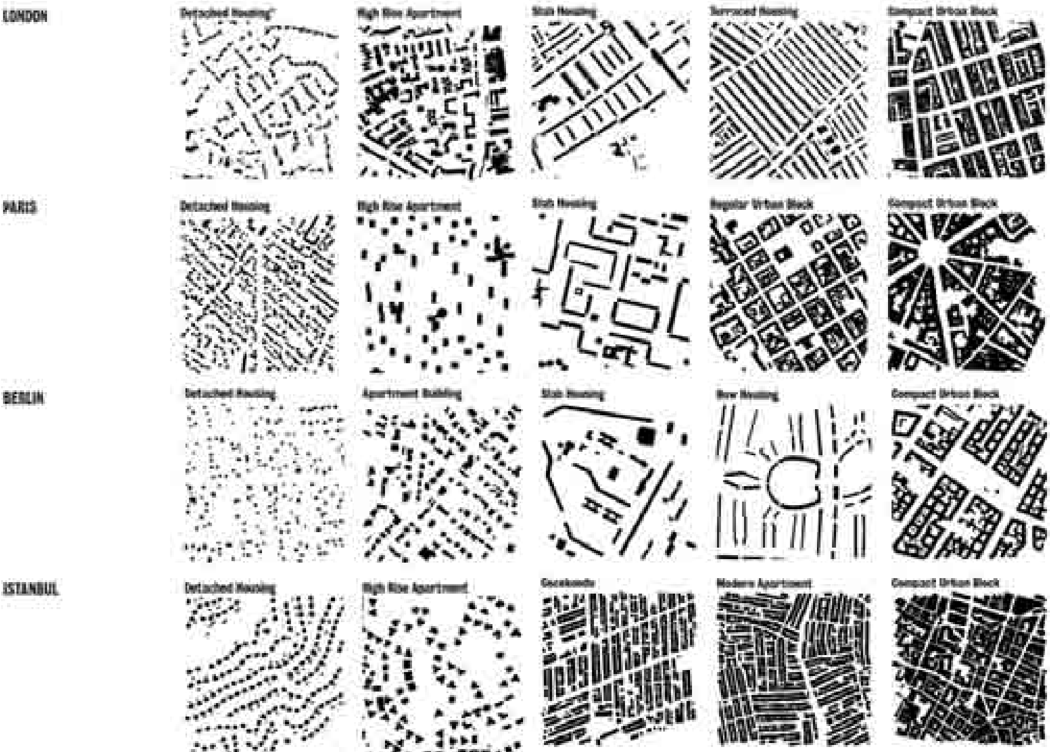

Fig.4-35 Urban samples to define urban morphology (LSE Cities & EIFEL)

to estimate heat energy demand at urban scale. Samples with taller average building height showed a lower demand. Surface to volume ratio was found the variable with the second strongest correlation. Energy demand decreased when the relative exposure of the envelope to the floor area was lower. Building density was likewise considered another good indicator. Denser areas had a lower heating load than low density samples. Despite the apparent influence of all these three factors, the interrelation between them seemed somehow neglected. Taller buildings tended to be associated to higher densities and compactness. In theory, it is possible to combine low density and tall buildings but it rarely occurs in real cities. Therefore there were underlying patterns which may have affected the results. On the other hand, the study focused on heating energy but it neglected lighting and cooling demand, which is likely to outweigh potential savings in many European capitals (for instance Istanbul, which was one of the study samples). Urban policies that embrace this study would probably advocate for taller buildings and denser cities. Whether this would eventually be positive for reducing energy consumption in buildings has not been proved though.

4.3.9. Energy analysis of urban form. Specific models

Although guidelines have been meaningful in providing a specific quantification of the consequences of different urban layouts, current practice tends to require ad hoc analysis for every particular scheme. Advances in computer simulation tools (thermodynamic models, generative design...), have engendered, on the one hand, new architectural and urban forms that cannot be easily accessed by rules of thumb or basic principles and, on the other hand, sophisticated energy models that can be integrated within the design process.

Urban designers are also reluctant on energy determinism. Energy factors alone are unlikely to determine many aspects of urban form. A good view or the existing urban grid may be stronger reasons to decide a different orientation. The urban character implies the acceptance of certain constrains and when constrains are overcome by design and creativity, conventional guidelines are too general and vague. In the last years new design methods have incorporated environmental analysis to assess the expected outcome of alternative solutions. Detailed models are used to replicate the site and the proposed schemes to inform design decisions (fig. 4-36) beyond the deterministic approach of standards. Current research is not delivering general guidelines but more detailed and form specific catalogues of urban forms and their related building energy performance. Recent publications have demonstrated this trend. A consortium of Danish institutions has examined eight urban superblock typologies[95], with ten variations within each typology to assess their performance in terms of energy, daylight, and outdoor comfort. The research focused on high dense urban areas and compact buildings. The initial hypothesis conjectured on the beneficial aspects of those parameters. Arguments were profusely illustrated with eye-catching graphics and architectural models (fig.4-

95 Pedersen, 2009

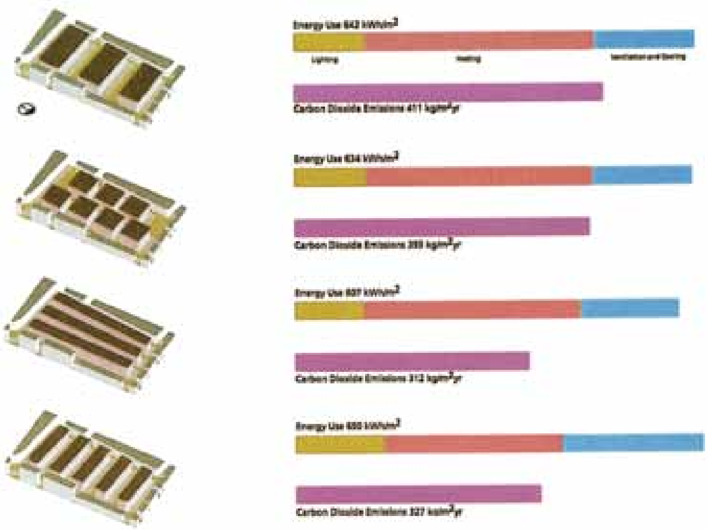

Fig.4-36 Energy massing studies for a Central London site, showing energy and carbon dioxide emissions associated to each option (Behling,1996)

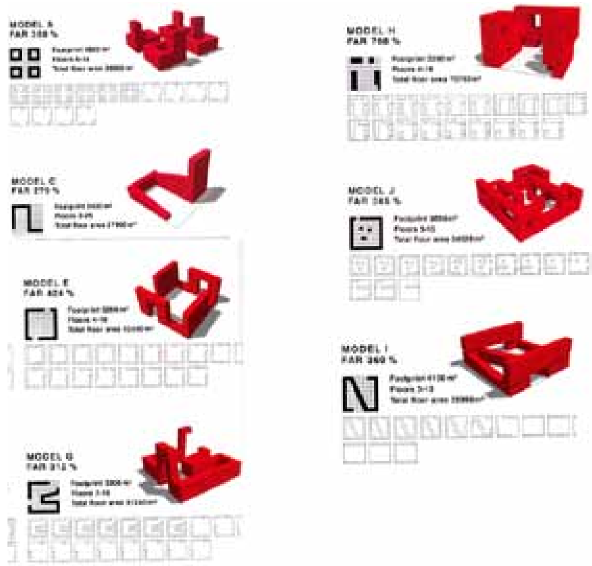

Fig.4-37 This study conducted a Danish group analyzed 80 different urban forms. The collection targeted high density and compact rather blocks (Pedersen, 2009)

37). However, the overall impression is of a mere collection of rather random shapes that are related to performance values. It lacks the clarity and soundness of classic guidelines as computer generated results are not always intuitively understandable and the causal relation is somehow missing during the modelling process.

4.4.Skepticism and softer alternatives

Many urban students have declared their skepticism about both energy considerations at urban scale and the benefits from drastic spatial policies in the existing fabric. Owens, for instance, argued that energy factors had never induced urban change and they are unlikely to do it unless there is a radical increase in energy pricing[96]. She admitted that different urban arrangements could make a difference but, she argued, non physical alternatives, such as fuel substitution or micro-level improvements "within the same shells"[97], could deliver similar results without dramatic changes in the urban structure. The slow turnover rate of the building stock and the institutional rigidity are further constrains that discourage energy driven physical transformations. She identified, however, several urban parameters that are inherently energy efficient: compactness, density and mix land use. Dense, compact areas with a diverse range of functions have the potential to deliver buildings with a lower heating demand while enabling the implementation of more efficient systems, such as district heating and combined heat and power[98]. The energy savings from passive solar design were estimated around 12%, whereas the use of combined heat power could grant savings in primary energy up to 100%[99]

The mixture of activities is an urban parameter whose benefits are commonly circumscribed to a reduction in the need for travel. However, there are, potentially, further returns for building energy savings when different functions coexist in an urban area. Rickaby[100] highlighted the great variation in the internal gains generated by different functions. Catering facilities, for instance, could produce around four times more heat than a conventional office. This could be use to arrange activities in a way that those which needed better solar access were located in south oriented frontages, whereas building types with high internal gains, and therefore not so dependent on solar energy, could be placed on the north oriented street elevation. Local heat recovery and district systems would also become feasible by the mix of activities.

What all these studies have in common is that energy performance of urban buildings is constrained by urban form characteristics and, although many improvements can be undertaken at building level, the limitations at urban scale may prevent the full potential of savings being realized. If planning and urban design integrate energy criteria, it would be possible to decrease fossil fuel and carbon emissions from buildings. The integration would address both the existing city and prospective growth as they have different priorities and constrains.

96 Owens1987
97 Ibid
98 Ibid p. 179
99 Owens, 1992
100 Rickaby, 1987

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Fig.5-1 Commuters at Canary Wharf tube station, London

CHAPTER 5

URBAN FORM AND THE IMPACT OF TRAVEL

5.1 Introduction

After discussing on urban form and building energy, the focus moves now to the analysis of mobility and its connection with the spatial structure of the city. Any study, policy or measure that targets urban energy performance needs to consider the impact of travel patterns. Otherwise, the potential benefits could be outweighed by an unforeseen increase in fuel usage, car dependence or any other travel related imbalance. Indeed, transport is the biggest sector in energy consumption in Europe (31% of the total)[1], followed by the domestic and industrial demand. Although part of inter-metropolitan interactions pursued by motorised travel are determined by socioeconomic factors, an important proportion of transport activities can be influenced by planning at city or regional level. The era of cheap fuel and general motorisation fostered urban sprawl from the mid 20th century. Developing countries have now adopted a similar model but prospective fuel shortage may force the cities of the future to rethink their communication systems in order to adapt them to increased travel costs.

This section begins with a general introduction to the principles of urban travel, the associated impacts and the trends that have been identified in recent years. Energy and carbon emissions are addressed in the initial paragraphs to put the problem in perspective. For a clear understanding of the approach and subsequent analysis, some of the main concepts related with the topic, such as activities and modes of transport, are discussed in following sections. A second part focuses on how aspects of urban morphology and socioeconomic variables may influence travel patterns in cities. This is not a straightforward task as results from previous studies are mixed and controversial. An introductory explanation of the main research methods, with an especial attention to Land Use and Transport Interaction models (LUTI), precedes a review of precedents and selected literature. The final synthesis is based on a recent meta-analysis, which is complemented with further European examples. The insights from this section will be carried forward for the development of methodological instruments and the analytical work of following chapters.

1 Eurostat, 2012

5.2 Transport and Energy

The connection between transport and fossil fuels is so strongly rooted in the collective conscience that the idea of a post oil age seems to pertain to the field of Science-Fiction. The serious consideration of this issue has been postponed during the cheap oil age. Factors such as flexibility and limitless mobility have outweighed energy in transport in decisions at all levels, from households (e.g. planning holidays) to governments (infrastructure budgets). This seems to contradict the fact that most OECD nations are strongly dependant on petroleum imports, whose price may be affected by shortage and a raising demand from developing economies. Nevertheless, conflicting interests prevent those countries from being fully committed to reduce their “addition to oil”[2] in the short term. Car related industries are too important to national economies. New roads and motorways are being continuously built and fuels prices are being kept still relatively low. Some decisions are taken as if fuel production was unlimited. Nonetheless, according to generally accepted estimates[3], oil production is about to reach its peak in the next few years and world reserves will be practically depleted by the turn of the century. Despite the intense prospecting for new oil pockets in deeper areas and the exploration of alternative energy sources, such as hydrogen or electric batteries, the maps of world mobility may be radically different for the next generations with respect to how they look today (fig 5-2).

The end of the carbon era does not necessarily mean the end of travelling. Human endeavour has produced numerous alternative modes of travel that, even for long distances, do not require the use of fossil fuels. Military campaigns and overseas trade, very often closely interrelated, stretched over thousands of miles and across seas and oceans since ancient times (fig.5-2). Almost the entire coastline and a great part of continental land had been surveyed before the industrial revolution. On the other hand, current communication technology has turned physical travel into a conscious choice rather than an actual need in many cases. Future cities need to be adapted in order to provide accessibility and opportunities to a population that may see as their spatial mobility is

2 In reference to George W. Bush’ notorious State of the Union speech pronounced in 2006. See also Friedman, 2008

3 Roaf et al, 2009

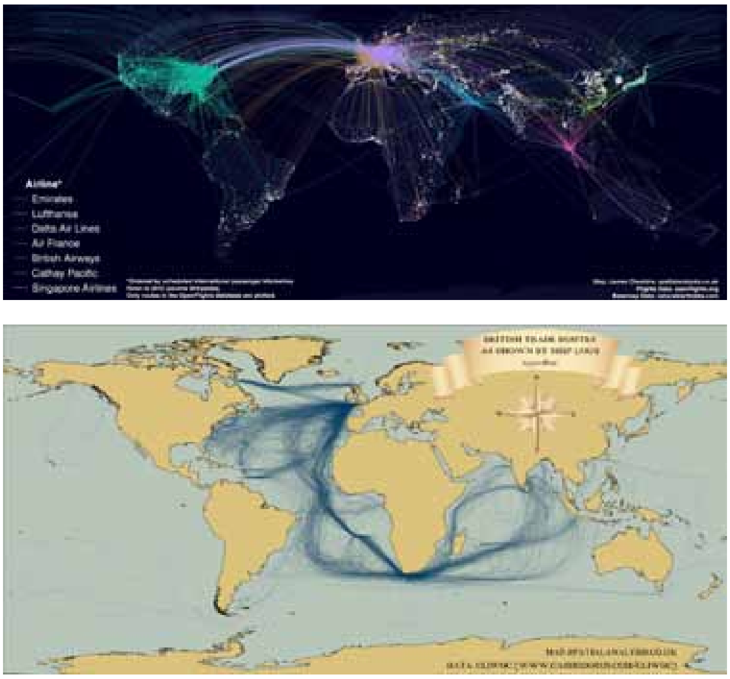

Fig.5-2 Top: Current worldwide mobility. Routes flown by the seven top airline companies in terms of passenger-km (Cheshire, 2012a) Bottom: Historic worldwide mobility. Trading routes of British ships 1750-1800 (Cheshire, 2012b)

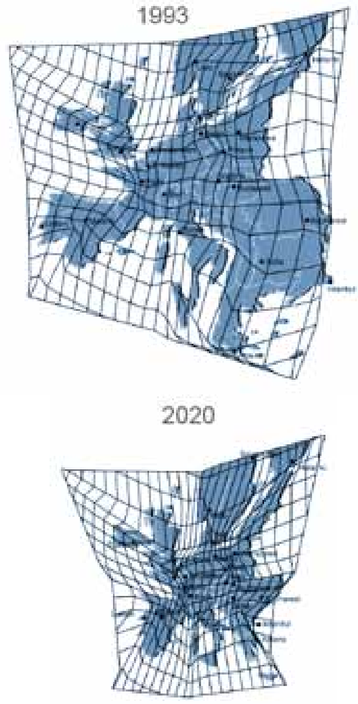

Fig.5-3 Time-space maps of rail travel times 2020 and 1993 (source: ESPON, 2003)

gradually limited while their dependence on interaction increases considerably.

Paradoxically, one way to prolong the current carbon era is by reducing transport consumption. As resources are limited there are only two options, either they are intensely used and depleted in a short period of time or they are rationed so that they last longer. Previous graphs (fig. 4-8) have shown how energy demand of transport represents one of the main factors of the energy consumption in European countries. Despite improvements in technology and fuel efficiency, the potential benefits are being outweighed by changes in behavioural patterns. Demographic growth, welfare and network capacity have increased considerably in the last decades while journey costs, both in time and price have been reduced in relative terms. The mere act of travelling has become attractive per se. It is affordable, comfortable and it provides an escape from daily routines, not to mention a sense of social status. As a result, the average distance travelled per person has increased around thirty percent in the European Union since 1990[4]. A great part of this growth can be explained by the use of private car alone, which has been increased in a similar proportion of one third[5]. The flexibility and independence provided by the car have had a two-sided effect in urban development. It allowed the suburban explosion and the use of the car was enhanced by the longer distance between suburban residential areas and central employment centres.

5.3. Environmental Impacts from Transport

The increase in transportation has become an environmental problem with multiple derivations and extensive effects upon natural and human ecospheres. The most important impacts can be categorized in these topics[6]:

- Climate change
- Air quality
- Noise
- Water quality
- Soil quality
- Biodiversity
- Land take

One of the most widely studied impacts relates to the emissions generated by fuel combustion. In a global perspective, CO2 transport emissions represent about thirty percent of the total emissions in OECD countries[7]. Looking

4 Bannister, 2011
5 Ibid
6 Rodrigue, et al 2006
7 Estevan and Sanz, 1996

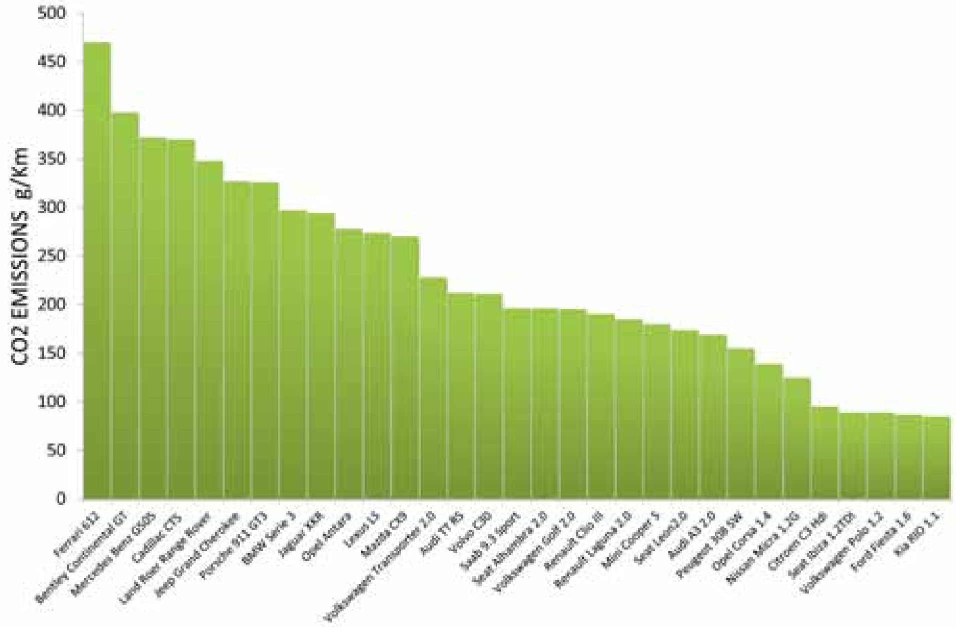

Fig.5-4 CO2 emissions for different car models. The most inefficient cars emit over five times more CO2 than the best performing (data: IDAE-ANFAC-ANIACAM, 2012)

back to figure 4-8 it can be seen that transport accounts for about one third of the overall energy consumption in those countries. The consequences of carbon emissions in climate change and global warming are well documented in numerous reports[8] and its thorough discussion goes beyond the scope of the present work. Nevertheless, the energy and carbon efficiency of mobility are considered as important criteria in urban performance assessment.

The reduction of motorized travel in cities has further potential advantages. In addition to the direct consumption, there are diverse impacts that could be mitigated alongside a decrease in transport. Cities would become healthier as the improvement in air quality would be an immediate side effect of a reduced presence of cars. Transport combustion generates not only carbon emissions but also other chemical substances such as Nitrogen Oxides (NOx), Sulphur Dioxide (SO2) and other Volatile Organic Components (VOC) that, in large concentrations, are highly pernicious for human health, especially for cardiovascular and respiratory systems. Unlike other polluting agents, the effects from transport contamination are closely connected to the point of production or, in other words, vehicles pollute as they go (through the exhausts). In open and permeable areas, such as rural zones or low dense neighbourhoods, moderate emission levels can be dispersed naturally by the effect of winds and natural atmospheric processes. Unfortunately, the greatest concentrations tend to occur in dense urban centres, where it affects more people and the built fabric precludes air movement and, consequently, the adequate dispersal of contaminants.

The car is the usual suspect for the poor quality of the urban environment due to its high impact on air quality. According to some estimates, private cars and taxis account for 80% of transport pollution[9]. It is not strange then that many studies have targeted the automobile dependence and its connection with city form. The most influential of all and, perhaps also the most controversial, has been the world wide survey conducted by Newman and Kenworthy[10] in the ninety eighties. They collected data for over 30 cities around the world to indentify correlations between urban form and automobile dependence. The data had initially confirmed a strong correlation between density and fuel usage. Their findings were repeatedly quoted by environmental and urban students thereafter, although various critic voices had fiercely challenged their main arguments, especially in the United States[11]. These critics claimed that the report failed to consider socioeconomic aspects and that the analysis was reductionist, deterministic and too focused on a single aspect[12]. On the other hand, had the report focused on urban air quality, results would have been different as, although overall emission and energy consumption may be lowered with densification, the high concentration of pollutants that results from it could be hardly considered as a positive outcome. Cities should be considered as especially sensitive environments as the combination of people and limited permeability can generate harmful effects for human health. Densification policies should, therefore, be accompanied by other measures to control the side effects in air quality. There

8 See for instance, the Intergovernmental Panel for Climate Change reports: www.ipcc.ch

9 Pozueta, 2000
10 Newman and Kenworthy, 1989
11 Gordon and Richardson 1990 Jenks et al 1996
12 Gordon and Richardson 1990 Gómez Ibañez 1991

are examples such as the congestion charge, which decreased traffic around 25% in central London[13]. Other alternative that is currently being proposed consists on the taxation of the most pollutant vehicles. A comparison of emission rates across the spectrum of car models shows variations of factor five (fig. 5-4). Typically, the most inefficient models correspond to luxurious brands with a great cylinder capacity, which are affordable only to wealthiest classes. Notwithstanding ethical aspects, taxation may still have a limited impact as to discourage the purchase of these cars. Higher running costs would make these cars even more exclusive and therefore more attractive to wealthy buyers. Absolute ban would be undoubtedly more effective and immediate savings in energy and emissions could be delivered.

In addition to car traffic, attention must be given to the pollution generated by other transport modes that operate in or around cities. Transport terminals, logistic centres, ports and train stations are particularly vulnerable as their activities concentrate a great number of highly polluting vehicles. The location of these facilities in the city should be considered together with prevailing winds to mitigate the spread of pollution in the urban environment. In recent years, the case of Hong Kong harbour has become a notorious example of high pollution levels derived from freight. The container port of Kway Chong, which is located next to a residential area with half a million residents, receives around 12.000 ships and a much higher amount of trucks every month. Several measures, from fuel switches to city-wide ventilation regulations[14], have been implemented to improve the air quality in the area. Lower emission agreements were also implemented in ports in the Baltic Sea, the English Channel or Los Angeles.[15]

Externalities from transport

The concept of externalities addresses the distribution of the impacts from activities at the generation and beyond. It considers the share of those impacts between interested parties (i.e. stakeholders) and the rest of the society. The externalities from transport can be divided in social, environmental and economic costs:

- **Social cost**. Motorized travel has increased and extended the risk of accidents, especially when cars are involved. Although figures tend to diminish, casualties are still high. In 2012, 1,484 persons died by car accidents in Spain. It represents a 70% decrease respect to the number of casualties in 1992[16]. Road improvements, better and safer cars and social responsibility are some of the reasons for the decrease of fatal accidents. Indirect impacts also affect the life quality of urban residents, regardless of their use of transport systems. As mentioned in previous paragraphs, air pollution affects respiratory and cardiovascular systems that may eventually imply disease and the need for medical treatment. Some authors argue that life expectancy may be also reduced due to transport emissions[17], although it is difficult to quantify the extent of this. Noise from the traffic has been signalled as one of the main issues in urban areas. Chronic exposure to noise is associated with increased risk of heart disease, hear impairment and mental health issues[18]. A recent study conducted in twenty five European urban areas reported that above half the population was exposed to noise levels beyond the recommend threshold of 55dB[19](fig 5-5). In Spain, 23% of the population (urban and rural) is reportedly exposed to noise beyond tolerable levels (65dBA according to the Department of Environment), this is the highest value in the OCDE and it is notably worse in urban than rural areas (65% in Madrid, 52% in Barcelona)[20]
- **Economic costs.** The economic externalities of transport are diverse and of a great importance. Subsidized infrastructures, fuel and other services (trains, low cost airlines) have imposed a burden upon all taxpayers, even if they do not require travelling. It is considered that improved mobility benefits the economy of a region and, for that reason, subsidized schemes operate in motorways, airlines and public transport. This question is often alluded when a rise in public transport is decided on the grounds of a fairer distribution between taxpayers and fare-payers. Infrastructure provision is normally funded by public administrations which need to balance the geographic distribution of their investments. That does not necessarily respond to strategic economic priorities but to compensatory decisions. Congested cities and traffic jams decrease work productivity when working hours are wasted in travelling. Several studies have estimated the number of man-hour lost due to congestion: for North America there were over one billion wasted hours in 1986 whereas in Madrid it was estimated around 250 thousand hours per day[21]. Traffic pollution can be also cause of economic externalities. It affects the health of the workers and their productivity. On the other hand, because it can cause damages (spills) on agriculture, farming or fishing activities. Finally, the construction of a transport facility, especially if it has a great capacity and it does not provide further accessibility to the local community (e.g. highways, railway tracks or airports) is likely to reduce the economic value of

13 Bannister, 2008
14 Ng, 2009
15 Hora, 2010
16 DGT Spain
17 Rodrigue et al 2006
18 EEA , 2009
19 Ibid
20 Pozueta, 2000
21 Pozueta, 2000

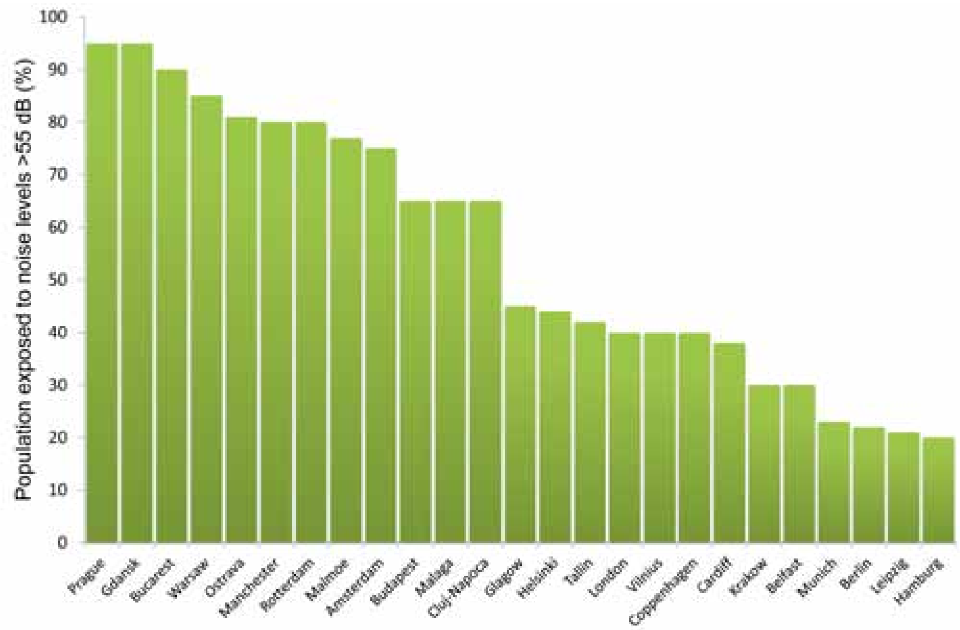

Fig.5-5 Percentage of people living in European urban areas exposed to noise levels above 55dB (data: EEA 2009)

nearby properties, since they will suffer the effects from acoustic and air pollution.

- **Environmental costs.** As it has been indicated, transport has been identified as one of the major contributors to greenhouse gas emissions and Climate Change. Around 30% of the externalities related to transportation are related to the mitigation of Climate Change[22]. Natural ecosystems are affected by atmospheric and water pollution caused by daily transport activities. In addition, they are occasionally struck by accidents that often derive in ecological damage. Shipwrecks imply an important fuel spillage risk, even if it is only the fuel load that the ships use for their own motion. The case of oil tankers becomes much more dramatic. Millions of tons of petrol can be spilled over the coastline as numerous examples have shown (BP in the Mexican Gulf, Prestige, Mar Egeum and Urquiola in Galicia, Spain, or Exxon Valdez in Alaska). In cities, the oils, hydrocarbons and heavy metals deposited on roads by cars, trucks and buses are likely to end up in rivers and streams due to the washing effect of rain. The washing effect of storm water directs the compound of rainwater and traffic waste through the surface drainage system to discharge points. First seasonal rains are particularly harmful as they sweep contaminant particles from roads. A treatment system should be planned before the water is poured into a natural system. Common solutions include detention basins and water swales that reduce run-off and allow heavy metals to be filtered and broken down. The physical road network is also a cause of major ecological concern[23], both during construction and after, during their lifespan. The dense layout of the metropolitan transport infrastructure induces habitat fragmentation, which endangers survival of species and causes a loss of biodiversity in the region[24].

A report by the University of Karlsruhe in 2004[25] estimated the economic cost from transport externalities around 650 billion Euros in the UE-17, which is equivalent to over 7% of the GDP[26]. The main contributor was climate change, whose mitigation accounted for 30% of the externalities, closely followed by atmospheric pollution (27%) and car accidents (24%). Affections to hydrological systems accounted for 7%, the same as noise. Finally, landscape damage was estimated as 3% of the total.

5.4 The nature of Urban Mobility

Transportation studies encompass the mobility of persons and goods over the territory, by terrestrial, aerial or water systems. Many traffic flows stretch over long distances or respond to intercontinental exchanges. Other connections take place between cities or metropolitan systems as inter-metropolitan communication. In these cases, the factors that induce, define and moderate the intensity and mode of transport are not so much dependant on planning decisions but on broader socioeconomic aspects. It cannot be denied, however, that planning can, to some extent and in combination with actions

22 INFRAS, 2004

23 Forman et al, 2003

24 Forman, 1995

25 ATM, 2008

26 INFRAS, 2004

at different levels, turn a formerly decaying and forgotten city into a vibrant and attractive destination that, in this way, will encourage further travelling. The regeneration of Bilbao's riverside, which included the construction of Guggenheim museum, the Post-Olympic Barcelona or London's strategic reinforcement of its character as global cultural and academic hub are examples of cities that have succeeded in attracting millions of visitors every year.

However, studies on urban mobility have mainly focussed on the observation of regular travel patterns and, particularly, on activity trips generated by people living or working within a functional region. According to Banister[27], the current transport planning approach is based in two general assumptions:

- Personal travel is considered as a derived demand, this is, people do not travel for the sake of it but they do it in order to reach a destination, where some activities will take place. This principle is being currently debated as the action of travel has become attractive itself, sometimes regardless of the attraction generated by the destination point.
- People tend to minimize the cost of travel, both in economic and temporal terms. The improvement of transport systems has reduced travel times and cost per kilometre considerably. However, research showed that while travelling has become cheaper and faster, the distance and number of trips have increased, which suggests a maximisation of travel opportunities within the available financial and temporal budget[28].

As a result, more efficient vehicles did not lead to the diminution of transport energy. Rather on the contrary, an increase in the average trip distance and the frequency of travel can be found in most metropolitan areas. Population density has decentralized faster than jobs and services, as more people could afford to live and work in remote places, far from the urban congestion. It also increased their car dependence for other daily routines, such as shopping, eating out or leisure. The layout of transport networks, especially motorways and railway lines has been decisive in the shaping of metropolitan urban regions. People concentrated along roads or near transport terminals. The private car has greatly influenced the suburban spillage and, conversely, those residential low dense areas, where public transport is unfeasible, have encouraged the use of private vehicles. As many of those suburban enclaves did initially lack business or service activities, their residents still needed to travel every day to the city centre to get their workplaces, thus creating radial commuting patterns around a central hub. Residential decentralization was followed by the progressive relocation of companies in the urban fringe, where land was cheaper and the good communication counteracted the distance from business districts. Radial commuting patterns were replaced by edge-oriented flows[29] as workers travelled from one suburb into another, rather than choosing a residence closer to their workplace. Counteracting commuting is currently one of the main challenges of transport and urban planning, as it accounts for about one third of personal travel in countries such as Spain or United Kingdom[30]

5.4.1. Activities that generate mobility

Most of the travel demand is induced by activities that are undertaken at the destination points. Trips have a purpose, which is to reach places that provide the opportunity to perform desired tasks. Aimless travel is still negligible compared with purpose journeys. This is quite convenient for research, as it allows the inferring of patterns associated with activities and places. A destination point results attractive and generates travel as long as it is associated with one or more activities. When this occurs, it becomes a centrality that exerts a "gravitational" force that draws in visitors from surrounding areas. The intensity of traffic generated by the centrality depends on the type and diversity of the activities associated to it. Common activity led journeys in urban areas include:

- **Commuting to work**. Commuting is defined as a "regular journey of some distance to and from one's place of work"[31]. It is perhaps the most predictable travel activity, as the origin and destination are spatially determined and the frequency is defined by fixed timetables. High job density areas are potential attractors for commuters whereas residential mono-functional zones are likely to generate a regular outflow.
- **Commuting to study**. It is as predictable as the journey to work, or even more, as students can hardly enter or leave schools before the bell. In school holydays urban traffic becomes much more fluent at peak times since the congesting effect of school buses, parents escorting their children in private cars and double parking is avoided. Study-related commuting is not as intense as working flows but it is strongly concentrated at peak periods and it can compromise traffic performance in cities.
- **Shopping**. It can be divided in frequent or daily shopping, to purchase fresh food (groceries, bread...) and periodic shopping to acquire long-lasting goods. The behavioural patterns for each type of shopping differs as buying fresh food can be embedded in the daily routine and, in the logic of minimum travel cost, it may be undertaken as part of other purpose-journeys (such as going to work or escorting children to school) . Occasional shopping typically implies dedicated trips to specific places, such

27 Banister, 2008
28 Smith, 2011
29 Hall and Pain, 2006 p.37
30 DECC , 2011 Ministerio de Fomento, 2007
31 Oxford Dictionary of English

as shopping malls or department stores. Large shopping centres are important points of attraction that need good accessibility. The adoption of the American model of suburban malls has displaced shopping activities from their traditional location at central districts towards the periphery, with a consequent increase in traffic flows and car dependence.

- **Leisure**. Travel surveys include travel for leisure when the purpose of the trip is to reach a destination, but not when trips are themselves a form of recreation (e.g. yachting, horse riding...). Leisure has become a major travel purpose after the welfare state allowed wealthier households and unions achieved better conditions for workers, including paid vacations and longer rest periods. The nature of leisure travel is broad and diverse and it ranges from a dinner out, which barely affects traffic patterns, to large events such as concerts or football matches, which imply massive crowd movements that can overload the transport network capacity. Current technology allows the study of patterns on crowd movement by means of the interaction of people with their mobile devices[32].
- **Other personal business and travel purposes** may include bureaucratic procedures, medical examination and other social events that cannot categorized as leisure, such as religious ceremonies, funerals, or courtesy visits to hospital patients. In some of these cases, the regular flow of in-house workers is increased with a fluctuating flow of external visitors.

All these activities have a physical translation in the structure of the city, a stadium, a hospital or a business park, are net attractors of urban trips. How these facilities are integrated in the urban structure and transport systems will determine, to a great extent, the traffic flows for different modes of urban mobility.

5.4.2. Modal choice

The transportation mode that users choose for a trip is influenced by a number of factors. Some of them have a socioeconomic character (income, age, preferences), but other factors are closely related to spatial and morphological and land use aspects (network layout, distance between activities, proximity to public transport stops, etc...). Some connections between trip purpose and the modal choice can be also identified. Regular activities such as working or studying can be easily programmed in coordination with public transport schedules and they get embedded in daily routine. Unfamiliarity with timetables and fewer options may, in contrast, encourage the use of private cars in occasional travelling. The study of transport modal share and its correlation with urban morphology is critical to understand the energy performance of cities due to the different efficiency of each transport system. The energy used in a particular journey is proportional to the distance travelled and inversely proportional to the transport mode efficiency (Km/Energy Unit). For practical reasons, a standard efficiency is assumed for each transport category, although variations within categories can be substantial. For instance, different car concepts present different levels of fuel consumption and CO_2 emissions (as seen in fig. 5-3). Passenger capacity, level of occupancy and the average speed of the vehicle are other factors that determine the efficiency of a transport system (fig. 5-6).

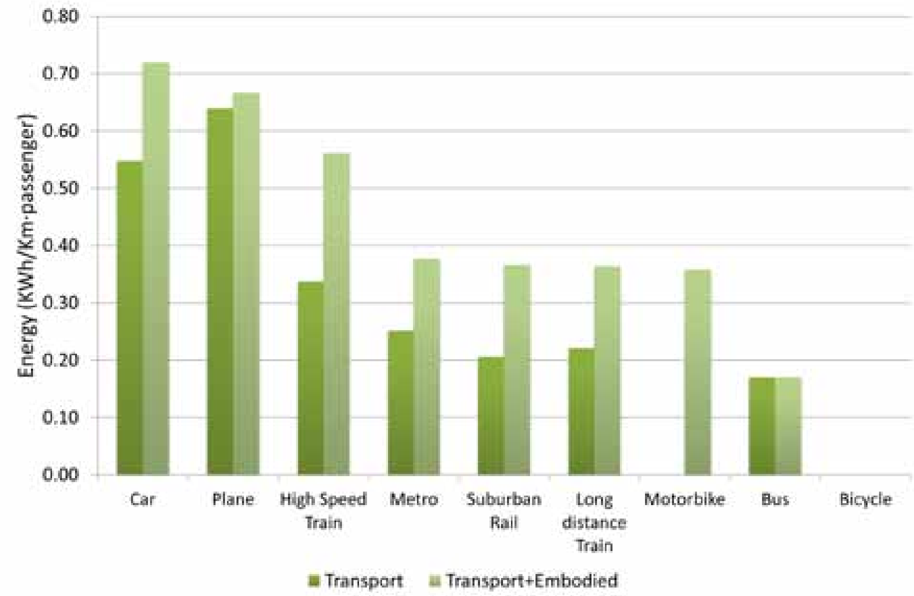

Fig.5-6 Energy per Km and passenger per transport mode from operation and total energy, including manufacturing process (data: Estevan & Sanz,1996)

32 Biderman et al, 2011

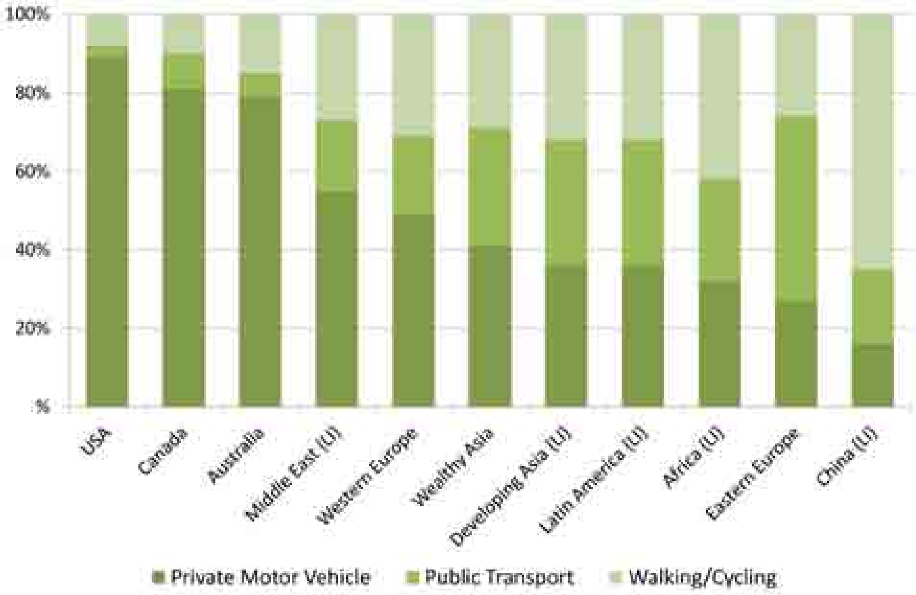

Fig.5-7 Modal Split for all trips in cities around the world, 1995 (data:Kenworthy & Townsend, 2002)

Fig.5-8 The electric prototype designed at MIT (Mitchell et al, 2010)

The main division of passenger transportation modes can be made between motorised and non motorised travel. The latter includes basically walking and cycling while the former can be further divided into private (car or motorbike) and public transport (bus, railway, metro). Most intra-urban studies do not account for air or maritime travel as they are hardly influenced by decisions or factors at city level.

5.4.2.1. The problem of the private car

Private car has become the most popular transport choice in the cities of developed countries (fig.5-7). They have reached an absolute predominance in North America and Australia. In European cities, the share of car mode accounts for around half of the total number of trips, ranging from lower values in Paris (33%)[33] or Barcelona (36%)[34] to the high dependence of London (63%)[35]. Car dependant cities are very inefficient since private vehicles consume, as average, more energy per kilometre and passenger than any other means of transportation (fig.5-6). Moreover, if embodied energy[36] is considered, car journeys could even result more energy intensive than air travel[37].Electric cars and hydrogen batteries are being proposed as cleaner alternatives to the combustion engine. An electric prototype designed at MIT is meant to reduce consumption by a factor of five, compared to conventional cars of a similar size[38]. In addition, electric vehicles do not release emissions at consumption points (unlike combustion engines), which would redound to better urban air quality. However, electric energy still needs to be produced somewhere else, thus the environmental effects of traffic are externalized from the urban system. A great proportion of electricity is still generated from "dirty" sources. In Spain, almost half comes from thermal plants (nuclear,

33 Camagni et al, 2002
34 Institut d'Estudis Regionals i Metropolitans de Barcelona, 2002
35 Department of Transport, 2002

36 Energy employed in the manufacturing of the vehicle
37 Estevan & Sanz,1996
38 Mitchell et al, 2010

Fig.5-9 Curitiba Skyline. The concentration of high density areas along transport corridors is visible in the urban skyline, in a clear manifestation of transport oriented city form (Magallhaes & Duran, 2009)

Fig.5-10 Spatial need for different transport modes (EC,2004) (reproduced from Berghauser Pont & Haupt, 2010)

coal or gas as primary sources)[39] and the transformation process had an efficiency factor of two (2 units of primary energy for each unit of energy delivered) in 2011[40].

5.4.2.2. Public transport

Notwithstanding the potential development of alternative technologies, public transport is, at present time, more efficient than private cars and, yet, it is not a panacea since it still requires a considerable amount of fuel to operate. An effective public transport line needs to work beyond a minimum threshold of its carrying capacity. Only when the collective transport carries enough passengers, is the normalized fuel consumption (litres per km per person) compensated by the number of passengers that share the same journey. The displacement of car passengers towards public transport system allows not only a reduction in energy consumption but also a more fluid traffic flow in the city. The physical space occupied by private vehicles is very large in proportion to passenger capacity (fig. 5-10). According to estimations, a typical bus consumes up to 24 times less space per passenger than a single car[41]. In the Paris region, cars take 94% of road space/hour but they only account for one third of the trips, whereas buses occupy as little as 2.3% of road space/hour for a share of 19% of the total trips[42].

39 MIEyT, 2011
40 Ibid
41 Cagmani et al 2002
42 Ibid

Urban form has demonstrably influenced modal share in cities. Low dense sprawled cities have historically encouraged the use of private vehicles in United States or Australia whereas compact European cities present a more balanced modal share[43] . Ingenious planning and design decisions can likewise reshuffle urban transport towards a more efficient distribution. It is considered that mixture and proximity of activities favours walking and cycling[44], while public transport needs a minimum density to become feasible[45]. One of the most paradigmatic examples of an urban structure as a realization of transport planning is Curitiba, in Brazil. The city has experienced an important growth since the 1960s. The urban expansion has been planned as a balanced combination of land use zoning and transport planning. The main arteries of the city define a radial structure with a higher concentration of jobs along these corridors (fig. 5-9). Residential densities are higher in public transport nodes, which operate under especial fare system that subsidizes longer journeys from poorer neighbourhoods. Building rights have been traded from property owners in low density areas to these zones of improved connectivity, to redistribute surplus values without compromising the feasibility of the spatial strategy. Recent reports have revealed that transport related energy consumption in Curitiba is around 20% lower than in similar Brazilian cities.[46]

5.4.2.3.Non motorized travel

Non motorised travel (walking and bicycle) is the only carbon neutral mode to date. Most of our historic cities were design or built before the automobile era and they are a good textbook on how to design *walkable* settlements. Empirical evidences have pointed distance as the variable that mostly determines whether a motorised vehicle will be used in a trip. For trips shorter than a mile, the probability of walking was reported above 70% while it decreased exponentially beyond that

43 Girardet, 2004 p. 138
44 Rogers & Gumuchdjian, 1998, Urban Task Force, 2000
45 Girardet, 2004
46 Maghallaes & Duran, 2009

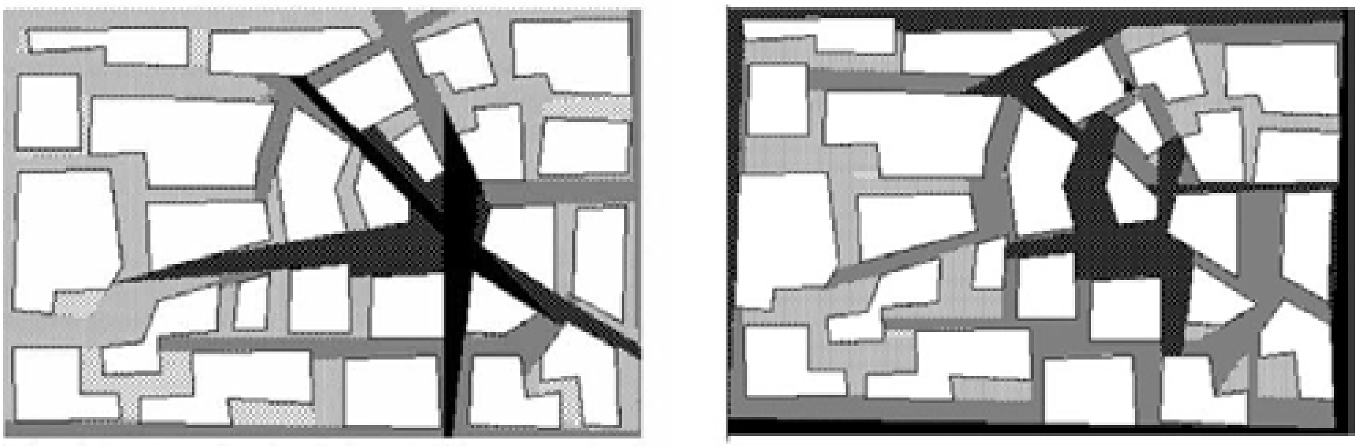

Fig.5-11 Visibility as related to pedestrian connectivity. Study on the effect of subtle changes in the urban fabric (Hillier, 2007)

threshold[47]. According to the same study, distances beyond four miles are highly unlikely to be covered on foot. Hillier and Iida[48] studied the psychological perception of the space as a factor that distorts the logic of distance. They found that the selection of routes by pedestrians did not respond to the logic of shortest itinerary but it had also to do with aspects of the visual field. Itineraries with higher visibility and more frequent connections were preferred by footers[49]. Topography, climate and safety are other relevant issues in pedestrian and cycling mobility whose effects can be partly mitigated by design. The combination of pedestrian routes with mechanical systems, such as elevators or escalators, to overcome topographic features has been explored in several cities, such as Barcelona (Montjuic, Forum) or Toledo. Covered passages, arcades and galleries can be found in the historic cities of rainy climates as a typical feature that affords shelter for pedestrians in their urban journeys. Cycling is being promoted as an alternative means of transport in recent years. The general use of bikes has been, until recently, unexpectedly linked to Northern locations, such as Copenhagen or Amsterdam, whereas in milder Mediterranean cities it was not nearly as popular. The integration of dedicated cycling lanes, together with greater traffic congestion and the setting up of efficient rental systems has turned the bike into a competitive transport option in cities like Barcelona, London or Paris.

5.5 Urban Form and Travel Patterns

5.5.1. Transport and Land Use Models

In this section, precedents on urban travel patterns are described and revised. Most of these studies were based on the analysis of key indicators to identify connections between travel and urban form. The methods to collect the information were basically one of the following:

- Empirical accounts of actual flows (fuel use, traffic accounts...)
- Questionnaire-based surveys, in which individuals stated their preferences or habits (travel mode, shopping routine....)

To compare the effect of variations in urban form, data from different locations was typically mixed and accounted for. In this way, there was a range of values for typical measures such as density or size, to elaborate the alternative scenarios. The basic hypothesis would be that if cities with a “D” value of a certain descriptive variable (e.g. density) had delivered some value around “T” as an outcome (e.g. number of trips by private car) and, another set of cities whose descriptive variable was “D/2” had delivered an output “T/3” then, for any other variable being equal, an increase in “D” would result in a rise of “T” in a rate of approximately [(3/2)*D]. This association could be also used to test prospective scenarios in the same location. In this case, the impossibility of gathering empirical observations for future scenarios would be overcome by the elaboration of models or mathematical representations of human behaviour based on established correlations. A model can be defined an abstraction of reality to represent and analyze relationships between systems. In an urban model, the systems of interest are activities and their physical residues[50] or, in other words, the urban morphology and the processes that determine it.

Early transport models were developed in North America. The rapid urbanization and the popularization of the car created congestion problems and the need for precise tools to forecast traffic flows. The first simulations were built on analogy to the Newtonian gravity model[51], mainly based on the mass and attraction in destination points but they neglected important aspects of land use[52]. Linear transport

47 Van & Martyn Senior, 2000
48 Hillier & Iida, 2005 Hillier, 2007
49 Ibid

50 Using Alexander terms (Alexander, 1966)
51 Wilson, 1997
52 Batty, 1976

models could hardly encompass the complexity of the urban phenomena. The mutual interferences between elements and exogenous factors could create serious discrepancies between actual patterns and the outputs of the model. An increase in traffic may, for instance, lead to congestion and longer travel times, which will eventually affect trip generation. A new road, in the other hand, improves accessibility and encourages further development. These processes generate a feedback cycle that determines a non linear evolution of the system. An alternative type of models was developed to address the interaction between urban activities and mobility, the Land-Use Transport Interaction (LUTI) models.

Classic models estimate travel demand in four sequential stages. Transport trips are generated based on land use, population and employement distribution, which are normally fixed. Trips are then distributed in the transport network and different modes. Each of these stages may consist on one or several sub-models within the main structure[53]:

1. **Trip Generation**. It can be estimated by regression analysis, a function of independent variables or it can be established as an outcome of the population groups within the origin zone and the observed travel behaviour of each group.
2. **Trip Distribution**. Locational or interactional models can be used to estimate the number of trips attracted by a zone (gravity models) or the trips from each zone to all the others (interaction)
3. **Modal Split**. The probability of travellers using a transport mode for a specific origin/destination pair is estimated
4. **Spatial patterns of movement**. All trips are arranged on the transport network, normally selecting the route of less resistance (in time or cost). Transport congestion caused by overloaded lanes operates as a feedback mechanism to the trip distribution stage. The iterative process converges to balance the model until the final solution is reached.

The Lowry model was the first to incorporate land use in a simple but powerful interaction between residential and employement locations[54]. It inspired a number of approaches which were based on the interaction between pairs of zones (origin and destination points) within a study area. These models (1) aim to predict the number of trips (T_{ij}) between the zones 'i' and 'j' of the city for each purpose, where O_i is the number of trip origins, D_j is the number of trip destinations to zone 'j' , c_{ij} is the resistance to travel (typically cost) from i to j and β is a measure for the impedance. A and B are factors to balance the total number of trips with the trips generated (O_i) and attracted (D_j)[55] :

$$\mathbf{T_{ij}=A_iB_jO_iD_j\exp(-\beta c_{ij})} \qquad \mathbf{(1)}$$

These interaction models were still static as the variables of land use were fixed. The move towards dynamic interaction between accesibility and development would come after one of the constrains was dropped and the number of trips became a locational variable, mainly dependant of the destination characteristics[56].

A number of models were produced in the first generation, most of them were commissioned by metropolitan planning agencies and were especifically calibrated for those specific areas. However, initial results were dissapointing and models were deemed by critics as too expensive, complicated, mechanical and, eventually, meaningless[57]. The crisis of the systems approach to planning led models to the sidelines until the mid eighties, when the advance in computing capacity allowed a refinement of the original formulations. Contemporary urban models have been reviewed in recent papers[58]. Wegenner compares twenty of them in terms of applicability, operationality or structure among other parameters. Only few of the models were intended to go beyond the particular region for which they were created and can be applied in different contexts (ITLUP, TRANUS, MEPLAN, DELTA)

Criticism to urban models have been softened and even some of the critic voices admitted that the early reaction against them was taken by "some reactionary city planners who used it to justify their resistance to learning anything new and to vindicate their current practices"[59]. Wilson argues that modelling is connected to urban theory as it offers a framework for carrying theory as well as a basis for futher theoretical development. He foresees dynamic modelling as an instrument that allows better judgement on the validity of predictions.[60]

5.5.2. Indicators, variables and methods

The estimation of variations in travel demand as induced by transformations in the built environment has been one of the most studied subjects in urban planning.[61] The access to large datasets on urban mobility has stimulated a generation of studies that aimed to connect travel patterns with urban morphology. The initial hypothesis of most of these investigations assumed that spatial variations in the city would have an effect in transport trends. Data from real cities was used to compare scenarios that were represented by the differing spatial attributes (density, size) and the characterization (core city, satellite, village...) of those cities. In the absence of empirical data, mathematical statistical

53 Rodrigue et al, 2006 p.198
54 Wegener, 2004
55 Wilson, 1997
56 Ibid
57 Ibid
58 Geurs & van Wee, 2004 Wegener, 2004
59 Lee, 1994 quoted in Wilson, 1997
60 Wilson, 1997
61 Ewing and Cervero, 2010

models were elaborated. It allowed a better control of variables but it added some degree of uncertainty about the reliability of the results. Measures of transport were typically obtained from surveys and data collected from transport authorities or other public institutions. The indicators used were not always consistent and they could include one or several of the following variables:

- Number of trips
- Trip purpose (work, shopping, leisure, personal business...)
- Modal share (motorised or non motorised, private car, bus, train, motorbike, bike...)
- Distance travelled (vehicle miles or kilometres travelled)
- Trip duration
- Fuel usage (or equivalent energy consumption)
- Carbon emissions
- Self-containment (percentage of trips within the study area)
- Commuting (percentage of trips outside the study area)
- Car ownership (number of cars per person)
- Road length per person

Fuel or energy demand and carbon emissions are the most synthetic indicators since they account for a combination of several factors. As the ultimate objective of these studies is not necessarily to reduce travel but to make it more energy efficient, the use of energy as an indicator has been very common. To estimate the transport energy consumption in the study area, information of modal share, vehicle efficiency and total distance travelled is needed at least. The methodologies followed to calculate energy from surveyed variables are diverse. It makes comparison and extrapolation difficult unless there is a thorough description of the computation process, including the assumptions that were taken. Several studies have based their findings in cross comparison of primary research. They gathered reports from literature and analyzed the common trends in their conclusions. Some of these studies are described in following paragraphs.

The built environment is, in these studies, described by variables that hypothetically influence travel demand. Cervero and Kockelman[62] introduced the idea of three D-variables: Density, Diversity and Design. In other paper, Ewing and Cervero added Destination accessibility and Distant to transit (public transport)[63] as factors that were typically used to represent relevant spatial aspects. They found that population density was the most commonly used spatial variable, followed by the mix of land uses (diversity) and job density.

The workflow of mobility studies inevitably begins with the compilation of travel data. The quality and level of aggregation of these data will determine the potential interest and the scope of the study. Small aggregation levels will allow intra-urban studies at neighbourhood scale and the establishment of meaningful correlations with spatial features in the same context. Citywide or above aggregates may result too coarse to be applied in urban planning as the generalization of findings from large to a lower scale is not accurate. This situation has been defined as "ecological fallacy"[64]. If the available data includes reliable information on key indicators (energy use, carbon emissions, distance travelled...), these can be used directly. Otherwise they have to be derived by computing other values and, perhaps, taking some assumptions in case of data gaps. The key indicator becomes, in this case, the dependent variable in a regression analysis in which spatial and socioeconomic factors (probably compiled from different sources) are the independent variables. The regression analysis provides an insight about the statistical relevance of each factor thus allowing the identification of those variables that most strongly explain the variations in the key indicators. Results can be simply expressed as the regression formula, in which case the sign and coefficient that accompany each independent variable indicate whether they have a positive or negative influence and their weight in the final value respectively. Other studies use elasticity, which is a concept borrowed from economics. It represents the ratio of percentage change in one variable associated with the percentage change in another variable. For instance, if the number sales of a certain product decreases in 30% when its price increases in 50%, the elasticity of sales to price is -0.6 (-30/50). If the output is a continuous parameter (e.g. fuel use, kilometres travelled) the value of elasticity can be interpreted as the variation in the dependent variable when the independent factor increases 1%, whereas if the output is a discrete value (e.g. modal share) the elasticity can be understood as a variation in the probability of falling within the category that is being analyzed. Results from regression analysis and elasticity can then be used prospectively in transport models to assess policies and planning proposals.

5.5.3. Key studies

The most influential and, at the same time, controversial study, to date, has been the report published by Newman and Kenworthy in 1989[65]. They defined automobile dependence as a burden for sustainable development and argued that there was a clear connection with the form of cities:

"*Automobile dependence exists where urban form and transport options are such that choices are limited to car use*"[66].

62 Cervero, & Kockelman, 1997

63 Ewing and Cervero, 2010

64 The Ecological Fallacy is a situation that occurs when an inference about an individual is based on aggregate data for a group

65 Newman & Kenworthy, 1989, 1999

66 Ibid

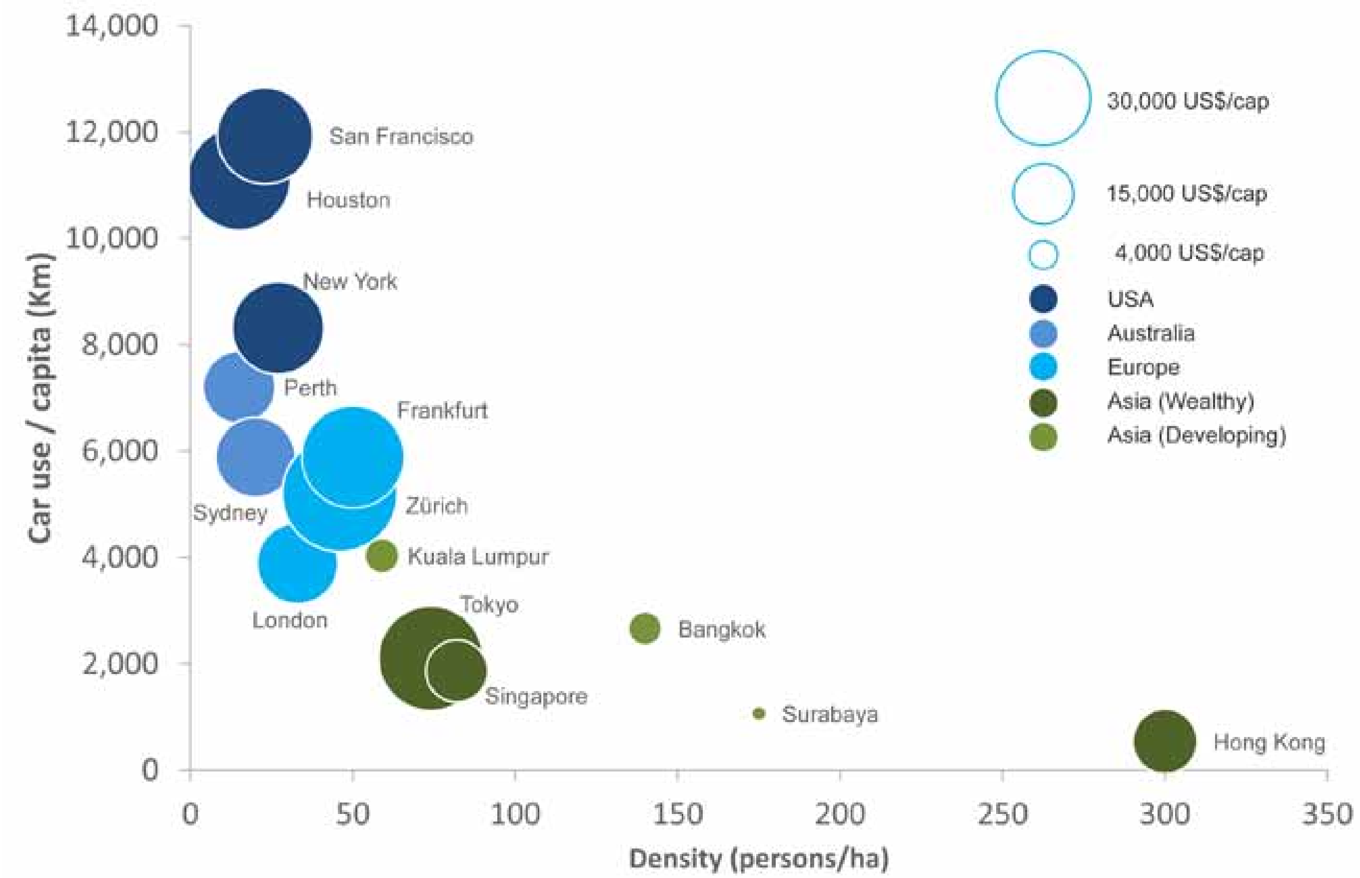

Fig.5-12 Correspondence between density, car use and wealth of cities. The data was used by Newman and Kenworthy to demonstrate that there was not a direct correlation between wealth and car use (source: author with data from Newman and Kenworthy, 2000)

They gathered data from cities all over the world and found a strong inverse correlation between density and fuel usage. High density cities, such as Hong Kong, Tokyo or Singapore were among those with a lower consumption whereas the American dispersed car-dependant metropolises invariably showed the highest levels of fuel demand. They concluded that around 60% of the variation in fuel consumption could be related to density. Their findings were used to defend densification policies as the ultimate instrument to achieve more sustainable cities[67] but they were also fiercely criticised by their American counterparts on the grounds of having neglected socioeconomic aspects, such as income or taxation[68]. Newman and Kenworthy replied with additional data to rebate the alleged influence of the economic context in their findings (fig.5-12). They argued that European cities were actually wealthier than American and Australian ones while their use of private cars was significantly lower. Similarly, developing Asian cities (Bangkok, Kuala Lumpur) were found to have greater car dependence than wealthier Asian cities (Hong Kong, Tokyo).[69] The data collected by Newman and Kenworthy has been re-examined a number of times[70]. In most of these cases the aim was to extract new insights and to fill the gaps of the initial report, especially the arguments that fed the main line of criticism, the lack of a multivariable analysis

A wide range of reports has been produced thereafter that differ greatly in methodology, context and scope. Some of them have focused specifically on land use and urban form while others have tried to encompass socioeconomic factors that were likely to determine, in combination with spatial aspects, transport and energy patterns. In general, empirical observations were preferred against computer models, although there have been some studies that used available models to simulate and assess different scenarios. The scale of the analysis was typically centred on the metropolitan region, so that aspects such as distance to city centre and connectivity could be included, while the unit of observation ranged from the neighbourhood to the entire city.

A review of these studies reveals mixed and ambiguous conclusions, as it has been pointed out by several

67 Urban Task Force, 1999
68 Gómez Ibañez, 1991 Gordon & Richardson, 1989
69 Newman & Kenworthy, 2000
70 As examples : Bertolini, 2005 Smith, 2011 Minaldi et al, 2004

authors.[71]Snellen suggests that the contradictory findings are due to the lack of methodological rigour that can be found in most of those studies.[72] Many of them, she argues, did not consider any differences in socio-demographic characteristics whereas the smaller group of rigorous examples seem to show only a limited role of spatial aspects[73].

5.5.3.1.Travel and city form

Despite its broad dissemination, Newman and Kenworthy was not the first study on city form and travel patterns. The initial explorations were carried out in American cities in the sixties to address the problem of congestions. Energy as a comprehensive indicator was used in a morphological study published by Sharpe in 1978[74]. He compared existing energy consumption patterns for Melbourne and made a set of forecasts with different assumptions for the year 2000. He created six scenarios to depict urban form and economic measures, which included low density fringe, satellite and directional development, high density redevelopment, increase in petrol prices and free public transport. The planning model TOPAZ was used to perform the analysis, giving trip flow volume, energy use and air pollution among other outputs. Conclusions showed that satellite development was the least efficient, with an estimation of 74 GJ/person per year whereas free public transport together with higher petrol cost would deliver the best results, with 57 GJ/person per year. If only the spatial scenarios are considered, the inner redevelopment, which implied a density of 125 persons per hectare (five times higher than in the other scenarios), was shown as the most efficient (64 GJ/person per year), followed by fringe (64 GJ/person per year) and linear developments (69-72 GJ/person per year). Therefore the effect of increasing density by a factor of five would barely decrease energy consumption around 10%, which seems relatively modest.

This research was updated by Newton twenty two years later[75]. For the same city of Melbourne he discussed five different forecast scenarios for 2011 (this is, in ten years future):

- Dispersed city, business as usual and continuation of low density development
- Compact city, increased population and higher density in inner suburbs
- Edge city, increased population and higher housing and employment density at selected nodes within the city. Orbital freeways linking edge cities
- Corridor city, is concentrated along linear corridors emanating from the Central Business District
- Fringe city, additional growth predominantly on the urban fringe

The environmental outcomes (energy, emissions, pollution) of the alternative scenarios are evaluated using the TOPAZ-2000 model. Dispersed and compact were shown as the two extremes in every variable, the former ensured maximum levels of energy consumption as well as carbon emissions, with values around 40% higher than in the compact city case, whose merits are notably more optimistic than Sharpe's predictions.

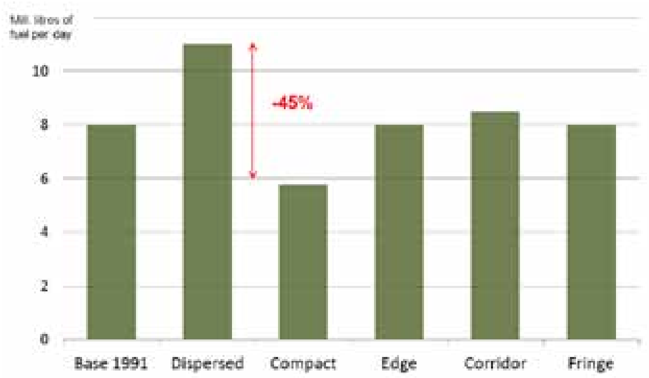

Fig.5-13 Fuel consumption for base case and five alternative scenarios of urban growth 1991-2011 in Melbourne (data: Newton, 2000)

Unlike Sharpe and Newton, Snellen based her study of city form in the empirical observations and surveys in eight Dutch cities[76]. The selection of cities was done so that they covered a wide range of urban forms and network structures. The city types were grouped in the following categories (fig. 5-14):

- Concentric
- Lobe
- Poly-nuclear
- Grid

While the network types were classified as:

- Radial
- Ring
- Grid

She analyzed the outputs from surveys in relation with socioeconomic and spatial variables[77] and found that travel time was hardly influenced by morphological characteristics, while it increased notably with social factors. She unveiled an underlying type of travel budget, which would be independent from spatial attributes and more connected to socioeconomic values. Respondents tended to maximize travel within their budget. Both travel time and distance were compensated between weekdays and weekend patterns, thus people travelling more during the week would travel

71 Banister, 2011
72 Snellen, 2002
73 Ibid
74 Sharpe, 1978
75 Newton, 2000

76 Snellen, 2002
77 Ibid, p.131

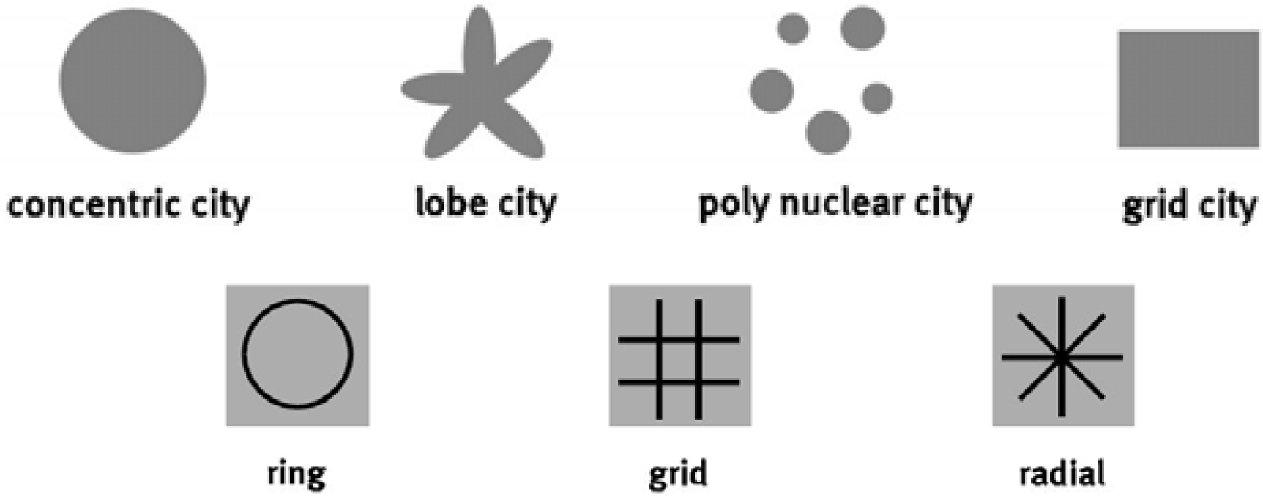

Fig.5-14 Urban shapes and transportation network cities in Snellen's research (Snellen, 2002)

less during the weekend and vice versa. She concluded that although the urban environment has a limited influence and it is weaker than socioeconomic aspects, the volatility of the latter is such (economic crisis, rise in energy prices...) that cities should be designed to enable people to reduce their travel needs and, in this way, become more resilient to the economic fluctuations.

A different studio tried to identify the correlation between urban development and the environmental impact of traffic in the Milan region[78]. Urban mobility was the dependent variable in a regression analysis with the following independent variables:

- Spatial variables: residential density, jobs density, size, urban development type (infill, extension...)
- Socioeconomic variables: Public Transport access

Following the findings from previous studies, high residential and employment density residents were found to diminish the impact from transport. The distance to Milan exerted very little influence in travel patterns although some industrial settlements seemed to be favored (less motorized travel) by being further away from the capital.

Breheny was sceptical on the potential savings connected to urban form[79]. He re-examined some of the main studies and policies elaborated in the eighties and early nineties (the paper was written in 1995) to challenge the paradigm of the compact city. He used data from a British study that looked into travel patterns in British towns and cities (ECOTECT)[80] . With that data he simulated scenarios in which he could test the effect of decentralization in transport energy. Instead of models or surveys he proposed a situation where decentralization had not happened and urban growth had been concentrated in cities instead of suburbs and satellite towns. He then assumed that travel patterns for different urban types would remain as identified by the ECOTECT survey, this is, the greater the population, the lower the transport energy per person. He found that current transport energy consumption would be 2.5% lower than without the decentralization process. He concluded by affirming that if containment policies were to be empowered in the next 30 years, the expected results would be in that modest order and, indeed, measures other than compactness could deliver similar or better results.

Karathodorou et al reached a different conclusion[81] using cross-national data from the Millennium Cities Database for Sustainable Transport[82]. They tested density against three aspects of travel: car ownership, fuel consumption per kilometre and annual distance travelled by car. Out of the three variables, fuel consumption per kilometre was found to have no statistical relevancy whereas the other two showed negative elasticity with density, -0.12 and -0.23 respectively. They estimated that fuel consumption per capita with respect to urban density of cities was in the order of -0.33. It means that doubling urban density would potentially deliver 33% lower fuel demand in urban travel, which is notably more optimistic than Breheny. An original argument of this study was the differentiation between short run and long run effects that they attributed to travel distance and car ownership. They assumed that the variation in the car stock and its composition is an accumulative process whose effects are developed over the long term. Finally, one of the most recent studies at city scale was published by Albalate and Bell[83]. They covered 45

78 Camagni, 2002
79 Breheny , 1995
80 ECOTECT, 1993
81 Karathodorou et al, 2010
82 IAPT, 2001
83 Albalate & Bel, 2009

European cities and followed the same method of regression analysis. In their conclusions they implied that urban population density has not statistical significance in transport energy and it is outweighed by economic variables and the fact of being a capital, which seems to push energy demand.

5.5.3.2. Intra-urban studies

The studies described in the previous paragraphs portrayed the city as a unitary entity characterized by global values such as density or population. They drew comparisons between metropolitan regions or defined scenarios of different city forms to evaluate the resulting patterns. The fine grain of the urban fabric was blurred and the whole urbanized area became a grey zone. Some authors argue that such level of abstraction is an oversimplification of the city and the generalization of such outcomes could be considered ecological fallacy. [84] Intra-urban studies analyze travel connections between different parts of a metropolitan region, observing the different textures and the complexity of the city and its parts. They take the neighbourhood or the district as unit of analysis instead of using aggregate data. The topology is as important as the absolute values because the relative position of the variables is taken in consideration.

A high proportion of these studies were conceived as supporting arguments for the principles stated by the "New Urbanism" movement[85], a theory that advocates for transit oriented developments and pedestrian environments in a sort of neo-traditional revival[86]. New urbanists propose an alternative model to dispersal and conventional infill based on the redevelopment of areas near transport hubs, considering three main characteristics:

- They contain mixed use and moderate residential densities (25-40 dwellings/ha)
- The street layout promotes walking, with a diversity of plot size and dwelling types
- There is close access to public transport

Cervero used data from the 1985 American Housing Survey to estimate the relationship between commuting modal choice with urban morphology and land use[87]. He confirmed that the probability of using the car for commuting was higher in low density mono-functional zones than in mid to high rise developments. With other variables being controlled, having tertiary uses within 100 meters (300 feet) of one's residence contributes to the use of public transport. It is alleged that commuters can conveniently shop while on their way to their nearest bus or metro stop. By contrast, if grocery or drug stores are located beyond 100 meters and yet within 1.6 Km, people are more likely to use the car as the distance is probably perceived as too far for walking while the flexibility of the car allows shopping in the way to work[88]. Cervero would reinforce these findings with new evidences in a follow-up analysis of San Francisco area[89]. In this new report the impact of spatial variables in vehicle travel is ambiguously considered as moderately modest but yet non inconsequential.

Buxton, on the other hand, calculated the potential car-related emissions associated to neighbourhoods designed under the premises of new urbanism. He compared them against conventional low dense residential areas in Australia[90]. According to his estimations, the residents of a traditional neighbourhood design would need, as average, half the energy required for travelling than typical suburban dwellers. He elaborated six scenarios in which the main variation was the proportion of new development that would be built as urban villages (i.e. under new urbanism ideas), while assuming the rest of the development as outer suburbs. Energy savings were around 14% for the scenario that contemplated 60% of new development as urban villages.

Masnavi presented another intra-neighbourhood study to evaluate the effect of density and mix of uses on the modal share in Glasgow[91]. He conducted surveys in four neighbourhoods of diverse spatial characteristics to find that the use of private car was up to three times higher in those places where density was lower. The mixture of activities was found to favour walking between areas of similar density.

Muñiz and Galindo included a notion of accessibility in their study of Barcelona's travel patterns[92]. They used data from surveys to infer energy consumption and the eco-footprint of personal mobility of the habitants of Barcelona Metropolitan Region in two moments, 1986 and 1996. Their findings confirmed some of the trends identified by previous studies. The ecological footprint (and therefore energy) was directly proportional to income and inversely proportional to three variables: density, jobs ratio and accessibility (proximity to the centre and to the transport axis).They looked thoroughly into the interconnections among supposedly independent variables (density and wealth, or proximity to centre) to avoid possible bias in their analysis. Following classic Bid Rent Models, they argued that density was closely related to accessibility. Those locations with better access would tend to get denser because they were more attractive for development. Their findings showed a strong influence of urban form in personal travel. They argued, indeed, that spatial factors would gradually become more important as a region becomes more functionally integrated. A similar study

84 Ewing & Cervero, 2010
85 Cervero and Kockelman,1997
Buxton, 2000
86 Calthorpe, 1993
87 Cervero, 1996

88 Ibid
89 Cervero, and Kockelman, 1997
90 Buxton, 2000
91 Masnavi, 2000
92 Muñiz and Galindo, 2005

was conducted for Surrey[93], a county to the South-West of London, which can be considered as a paradigmatic case of fringe or suburban development. The correlation analysis showed the linear association between urban parameters and energy consumption. Residential population density, distance from London and public transport accessibility were the most strongly correlated variables. Along the same lines, the authors confirmed that the significance of neighbourhood design was greater than previous literature had considered.

5.5.3.3. Meta-analysis

The conflicting results obtained by wealth of studies that analyzed the potential connections between travel and physical variables made both possible and pertinent the elaboration of cross comparative analysis to summarize and compare the observations from those primary reports. The main advantage of this type of analysis consists on their potential to identify common trends from the pool of samples. Any outcome that is consistent throughout a majority of studies can be considered as contrasted evidence. Ewing and Cervero have completed the most extensive meta-analysis on urban mobility carried out to date[94]. They inspected over 200 previous studies from which 50 were selected. To avoid possible publication bias, they used unconventional sources such as Google Scholar. The sample of studies covers primarily North American regions, although it includes cases in other locations, such as Hong Kong or Copenhagen. They summarized the more frequently analyzed variables in five categories:

- Density (population, jobs and commercial)
- Diversity (land use mix, jobs to housing, distance to a store)
- Design (intersections to street density, four way intersections)
- Destination Accessibility (jobs within one mile)
- Distance to Transit (public transport)

Some highlights were revealed in their meta-analysis for each of the main variables:

- **Total distance travelled**, they measured it as vehicle miles travelled (VMT). Destination accessibility (number of jobs within a certain distance) has an elasticity of -0.20, which means that for a double number of jobs within 1 mile, travel could be potentially reduced up to 20%. This connection is much stronger than the influence of population density, which is, in fact, relatively weak (elasticity of -0.04, barely a 4% reduction for double density). Design aspects have been seldom considered in transport studies and yet they seem to have a considerable impact according to the analysis. A road layout with short blocks and many interconnections favours the reduction in total miles travelled by car (elasticity -0.12).
- Regarding **modal share**, computed as the probability of a mode choice. The likelihood of walking is closely associated with aspects of design and diversity. The density of intersections seems to be a critical parameter in street design since it favours pedestrian use more than connectivity or any other of the analyzed variables. This finding goes in line with previous theories of spatial accessibility that brought in the relation between pedestrian behaviour and street layout[95]. The option of public transport is, as expected, more strongly associated with the distance to access points (i.e. bus stops or tube stations) than with any other parameter. The second and third most decisive parameter for choosing a public transport are intersection density and land use mix, which, according to the analysis, facilitate the efficiency of transit systems and therefore their use. One of the most controversial findings is the low influence of population and job densities in public transport use. It contradicts the intuitive notion of critical mass and density thresholds to maximize the number of potential "customers" in the catchment area.

Meta-analysis reveals common trends across multiple studies and thus it can help to discern sound and consistent insights from hyper-specific findings. The amount of studies collected and presented is a valuable tool itself that allows the comparison of estimations against observations. Results may be used to estimate the potential effects of urban transformations in transport trends. Even though average elasticity is not necessarily more accurate than that offered by some specific studies, it gives a sound idea whether there is any positive or negative expected impact from the alteration of spatial variables.

There are, however, limitations to the use of findings from Ewing & Cervero[96]. Some of them are explicitly stated by the authors. Firstly, the diverse range of methodologies that were followed by the different research teams casts uncertainty about the coherence of the results. Although the process of translating and reducing all outcomes to elasticity is described with great detail, some definitions are still ambiguous[97]. The large variations that were found between the outputs of the studies is another relevant issue. In some cases they found reports which were completely opposed to each other as they showed strong inverse and direct elasticity for the same pair of variables (e.g. walk trips per person to 4-way intersection).

93 Hickman & Banister, 2007
94 Ewing & Cervero, 2010

95 Hillier, 2007
96 Ewing & Cervero, 2010
97 For instance, "distance to nearest transit stop" has a literal meaning that seems to diverge from the interpretation of the authors. They speak of it as if it were a proxy for "public transport accessibility" which is confirmed by the fact that they present a positive elasticity between "distance to nearest transit stop" and "transit use" in a table.

That could be a sign of casual connections, weaker reports or the action of other underlying variables. The study has, moreover, a marked North American character. Only two out of the two hundred studies refer to European locations. Although they have only included studies that controlled socioeconomic variables, it is possible that profound sociocultural and geographic differences at both sides of the Atlantic determine some diverging travel patterns.

To counteract some of these issues, a selection of European cases has been analyzed in order to draw a comparison between them and the outcomes from Ewing and Cervero. The aim was not to re-elaborate the work using European data but to audit specific findings in order to test whether the identified trends are consistent with European samples. Eleven cases were initially selected from selected literature with two further additions from Ewing and Cervero review. The selection criteria were established on two main requisites: the statistical method and the comparability of variables. Six studies were finally chosen: Masnavi (2000), Snellen (2002), Naes (2005), Muñiz & Galindo (2005), Hedel & Vance (2007) and Hickman & Banister (2007). Unlike Ewing & Cervero, the results were not averaged as the reduced number of samples would limit this option. Instead, a summary was produced in which all the connections between travel and form were listed together with their elasticity factors[98]. The observation of common parameters and their comparison against Ewing & Cervero show similar trends. It confirms that, even though the accuracy of elasticity factors must be taken with caution, the sign and weight of spatial factors are consistent.

5.6. Discussion

The prediction of travel patterns based on general urban variables is highly questionable. Each specific case requires ad hoc analysis to reflect the particular contexts and the use of local data. Owens argued that exact predictions should not be the ultimate aim of planning analysis as “ we simply don´t know enough” and that flexible, normative planning should rather be based on “intelligent assessment of likely trends”[99]. The aim of this section was, precisely, to distinguish the trends which have been identified and corroborated by sound research. Much work has been done since Newman & Kenworthy triggered the debate about the effect of density on fuel consumption. Later research has convincingly demonstrated the relative influence of any single aspect in shaping travel behaviour in towns and cities. As the studies listed in this chapter corroborated, there is a current agreement about the multivariable nature of travel. The combination of factors and their relative effect in the different stages of travel demand prevent the formulation of absolute guidelines. Trends can be finely woven from the educated interpretation of reported observations at disaggregated level. The cross comparison of Ewing & Cervero and the selected European cases has been used to elaborate a matrix that illustrates those patterns that were considered more consistent (Fig. 5-15).

The matrix is divided in specific travel indicators (horizontal axis) and the physical variables that may regulate them (vertical axis), with the addition of household income as a key socioeconomic factor. These categories follow Ewing & Cervero nomenclature closely, as almost half of the values have been sourced from their report. Further categories have been added to the travel field as to include aspects that were addressed by other studies. Whenever evidences have shown connections between spatial aspects and travel, they are highlighted with a coloured square. If the square is green the correspondence is direct, this is, an increase in the physical variable is likely to favour an increase in that specific aspect of travel. It is the case, for example, of walking probability with respect to land use mix, the mixture of activities enhances walking as mode of transport. When there is an inverse correspondence, the square is shown in blue. The most intuitive case is the distance to public transport to the probability of using it. The longer the bus or underground stop is, the less probable it is to choose public transport for travelling. Finally, the size of the square illustrates how strong the connection between pairs is, according to the analysed precedents. The primary criteria have been the elasticity values as reported by the studies. The aim was to include only those connections for which there is a certain agreement, supported by evidence and research. The specific value of the elasticity is not considered as important as a notion of magnitudes and the sign of the influence, for that reason they have been grouped in four categories for each direct and inverse correlation.

The graphic display of those values offers a quick visualization in a format that is meaningful and legible for planners and urban designers. The merit of each spatial aspect is shown in relative terms and in connection to specific factors of the travel demand. The temptation of absolute statements based on linear causal relations (e.g. high density developments reduce transport energy) is softened by the presence of complex correlations with multiple factors. Some gaps in the graph could be filled through the interpretation of remaining relations. For instance, if “land use mix” favours the use of public transport and pedestrian trips, it could be inferred that it also reduces the probability of using the car. Since it also reduces motorised travel, it may be interpreted that it would eventually deliver a reduction in the energy consumption of transport. The matrix is therefore open to interpretation and it could be used as a preliminary checklist.

None of the variable pairs shows an overwhelming

98 In Hickman & Banister, 2007the value was not translated and it remained as in the original report, a Pearson correlation. It has been considered that it still gives an idea about the sign and strength of the connection (although not about the elasticity)

99 Owens, 1987

Fig.5-15 Influence of urban form and land use aspects in travel patterns according to the analysis of previous studies

connection, which confirms that travel behaviour is shaped by a combination of multiple factors. It may be pointed out the difference between a strong correlation in a specific pair and the eventual weight in the final impact by generated travel. For instance, distance to public transport is strongly connected with the possibility of using public transport. It does not result necessarily in a large reduction in travel impact as motorised distance could increase.

The matrix can be read from two viewpoints, from the spatial variables or from the travel factors. When it is read from the latter, the focus is on how a specific aspect of travel is influenced.

- The **probability of walking** is related with almost all aspects, although street density/number of intersections has a stronger influence, followed by a balance combination of jobs per housing and the mix of land uses. The distance to transport stops is inversely correlated, possibly because the lack of frequent stops enhances the use of the car.
- The **use of public transport** presents a similar profile as waking, with the exception of the distance to stops, which, in good logic, has a higher influence
- The **probability of using the private car** mainly

depends on average household income, the only non spatial aspect that has been included. Some studies have also reported a moderate inverse correlation with population density.

- The **total distance travelled by car** is a key variable in transport impact as it can be almost directly translated to energy and carbon emissions. Some factors that have been intuitively foreseen as positive for the reduction of motorised travel were highlighted in Ewing and Cervero study. The residents who live further from the city centre tend to travel more distance by car than people living in central locations. The connection between street density and intersections is less obvious, which may reflect that a more efficient network allows shorter routes. Population density and land use mix present a weaker influence, which contradicts some established assumptions.
- The **distance of each journey** is influenced by income. For wealthier households the cost of travel results more affordable and, therefore, the selection of residence and workplace may respond to aspects other than proximity. The connection with density and distance to centre is intuitive although not as strong as the economic aspect.
- **Total travel distance** is, in fact, a weak indicator since it typically includes all travel modes, public, private and non motorised. Typically, less total travel should imply less impact. However there could be exceptions in cases of very efficient collective transport that allows covering long distances at a reduced environmental cost. Density, distance to centre and distance to public transport are inversely related with total travel distance
- Finally, **energy consumption** decreases with high density and urban containment, although in a moderate correlation. The combination of other spatial variables may eventually affect energy consumption although they were not explicitly reported in the analysed cases and for that reason are not depicted. As it has been mentioned, the graph is open to that kind of interpretation.

5.6.1. Summary conclusions

The influence of urban form in travel patterns and transport energy has been examined in this section. In the first part, it has been described how the generalisation of travel has raised current expectations and distorted the notion of distance in developed countries. Home and work location or the place for shopping are often decided for non-spatial reasons (affordability, safety, status...). Travelling is economically affordable and the notion of maximising opportunities has led to a gradual increase in energy demand from transport activities, despite the advances in car efficiency and networks. Unless substantial progress is achieved in the field of alternative fuels, the current ease of travel is likely to change in the near future. A future in which the existing city is to persist as the physical framework for human activities. Whether current urban standards can meet the needs of future generations is in question. The externalities generated by transport are tolerable at present time because the economic returns from constant interaction are greater than the cost of the impact. However, this burden can become unaffordable if fuels is scarce and distances between activities and people continue to increase. The consideration of interaction and access in the short and long-term is, therefore, critical in the design and management of cities.

After the analysis of the most relevant studies in urban mobility, it can be concluded that, when it comes to transport, the physical form of cities matters. Some authors may diverge in the quantification of how much do spatial aspects influence travel patterns and how they interact with other socioeconomic factors, but none of the studies can conclude that travel is irrespective of the urban form and land uses. Contrary to mainstream theory, population density is not supported by evidence as the most determinant parameter of sustainable mobility. The arrangement of activities has revealed as more crucial than density. Greater improvements both in distance travelled and the use of non motorised vehicles can be achieved by proposing a balance between residence, work, services and leisure. Interestingly, a considerable influence can be exerted from urban design at street level. The network layout can enhance walkability. It has been demonstrated that having frequent intersections improves the visual percepetion of the urban space and, at the same time, facilitates efficient routes for public transport.

There is, nonetheless, a great scope for further research in urban travelling. The high expectations on density and the relatively weak association that was found with the main mobility indicators may be originated by a misinterpretation of the concept. Few studies have considered an alternative definition for the notion of density, most of them have used population, household, dwelling or jobs density. The intuitive connection of density with less travel was based on the false assumption that when the distance among people is reduced, they do not need to travel so much. What the studies have demonstrated is that people or jobs concentration do not work if they are not intertwined. Only when there is a mixture of functions can density deliver positive results and, even when that occurs, many other factors have to be observed, such as the social structure and its matching with the range of jobs in the area or the quality of the services and urban environment that the place has to offer. One of the tasks of urban design is to create places that enthuse people and that offer their residents a diverse range of opportunities for working, shopping and leisure thus effectively reducing their need for travel.

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CHAPTER 6

AN URBAN FORM ENERGY ANALYSIS AND MODEL

6.1. Context

People concentrate in cities due to the opportunities they offer and the promise of a better life quality. Indeed, a great part of the potential benefits of urban life are somehow related to social interaction. The proximity between individuals and large population concentrations are therefore considered positive factors to enhance urban success[1]. Mainstream theory defends that living in compact cities is moreover a very sustainable option.[2] A number of arguments are evoked to support this idea; the following are among the most repeated:

- Compact cities allow the confinement of impacts within the urban domain while the natural environment remains relatively undisturbed.
- Compactness reduces the physical distance between activities and, consequently, the need for travel is minimized.
- The concentration of people makes possible a diverse offer of leisure, culture, sport or shopping activities that ensures social enjoyment for urban dwellers.

On the other side, cities are sometimes perceived as prisons, places to be left at the minimum opportunity. The evil of urban congestion has been one of the main challenges of urban planning during great part of the twentieth century (Howard, Abercrombie's Greater London Plan...). Historically, those who could afford a retreat in the countryside would escape from cities whenever possible. Douglas has ironically described the migration of British pensioners from cities to rural retreats that he renames as "Costa Geriatrica" belts. The attraction generated by urban life does not seem to be so persuasive once the livelihood is ensured and businesses are over. There are important downsides associated to densification that may undermine the quality of the urban environment: air pollution, noise and traffic congestion have been reported as main problems in surveys conducted across European cities.[3] Eventually, the search for a good quality of life is a question of tradeoffs and personal priorities, "urban amenities against a better environment"[4].

Concerns about urban concentration are also shared by the students of the city[5]. The historic precedents, especially the industrial city and its slums, are still too present in planners' consciousness. Even if compactness were the solution, the traditional high-dense city design seems unfit to fulfill current expectations. Great advances have been made in the last decades in the field of urban analysis. Remote sensing, geographic information systems and big data sets have allowed researchers to unveil some of the unintended consequences of urbanization and associated processes in the urban ecosystem. These tools have been, however, more effective for drawing diagnosis than for assisting design solutions so far. The current moment in urban research is characterized by this dilemma. There is a great capacity to produce basic research, this is, to process data and to generate information, but there is a certain hesitation about the way to move forward or, in other words, what to do with all this information.

One of the fields, within urban science, that can greatly benefit from the new analytical techniques is environmental analysis. The energy evaluation of the urban built form has been broadly explored since the ninety sixties[6]. The investigation of energy aspects at urban scale had been limited by the complexity of the factors involved and the difficulty to handle large datasets[7]. Thermodynamic processes had been described and models were built with great precision at building scale. Current technology provides new opportunities to move beyond the assessment of individual buildings and to take account for the symbiotic interaction between urban buildings. Knowledge on building performance can be now extrapolated to a broader scale, looking into urban morphology and energy demand from a new, deeper and well informed perspective. Several undergoing projects have targeted the energy evaluation of large urban projects (CitySim[8], SunTool[9], Urban LT[10], ClimateLite[11], Ursos[12]...). However, few of them are actually available for planners and urban designers, which restrain the use of these applications

[<?>] Douglas, 1983 Glaeser, 2011 Frey,1999
2 Urban Task Force, 1999 Rueda, 1995
3 EEA, 2009
4 Ibid, p.11

5 Breheny 1995 Ng 2010
6 March,1972
7 Ratti et al, 2005
8 Robinson, 2011
9 Robinson et a,l 2007
10 Ratti et al, 2005
11 www.bre.co.uk/page.jsp?id=996
12 ursos.unizar.es

to particular academic and research environments. Ideally, such tools should consider the different levels of complexity and detail for each particular design stage. A model that is very complex and time consuming may discourage its use at preliminary phases, when accurate predictions may not be a priority. Given the nature of planning, many input parameters which are relevant to energy performance are still unknown, even at advanced planning stages. The identification of trends and likely patterns to be considered in planning prescriptions becomes more relevant than the accuracy of early predictions.

In this chapter, the elaboration and validation process of an urban energy assessment model is presented. From now on, this model will be referred to as Urban Energy Index (UEI). The UEI seeks to provide a quick method to undertake comparative energy analysis of alternative urban forms. It should not be regarded as an ultimate assessment tool but as an instrument to explore existing or proposed urban configurations. Although it has been inspired from energy models at building scale, it differs from them in scope and input parameters, which are quintessentially urban. The UEI aims to adapt well established calculation procedures to include only those parameters that are familiar for planners and urban designers, while leaving aside certain definitions that remain unsettled during general and development planning stages. It is a top-down assessment tool where variables at building scale can be assigned average values or modified within proposed bands. The most critical variables, those which define urban morphology, can be then manipulated so as to explore the energy consequences of different urban typologies. Several assumptions have been taken in order to simplify the operation and the number of input parameters. It has been noticed that these assumptions caused the tool to be more reliable in urban areas that have a moderate to high density. Rural or suburban environments, characterized by scattered houses with a great separation between them, could be rather considered and assessed individually, using any of the building energy models available. Therefore, the relative inaccuracy of the model in rural areas is not considered as a pitfall. The model does not address low density areas . On the other hand, it has been conceived with simplicity, speed and legibility as main criteria so that a high level of expertise was not a requisite to operate the model. Nevertheless, knowledge on environmental analysis is advisable for the correct interpretation of the results. The potential applications are diverse and they range from the assessment of a few urban blocks to city-wide heat mapping. The integration of the model in Geographic Information Systems has greatly expanded its potential use. It allows to take full advantage of synergies with rapidly evolving research disciplines such as data management and visualization.

6.2. Precedents

Two precedent models have to be acknowledged as having a special influence on the development of this application: the LT method and the Energy Index. They share some common characteristics such as simplicity and ease of use as being prioritized upon high precision. Although they were developed around fifteen years ago and it may be argued that there are more advanced computer packages currently available, their strength lays in their simplicity and the intuitive associations that can be drawn in a quite straightforward interaction. Both models are still valid. Either as background model embedded in broader software packages (i.e. LT in Climatelite) or as consultation spreadsheet for preliminary assessments of alternative design options and the setting of performance targets (EI). Other tools with same concept of simple evaluation at building scale have been recently made available at MIT and by Arup[13]. Although their operation and interface improve those of LT and EI, the transparency and easy access to the physical principles were the main criteria to select these as main precedents.

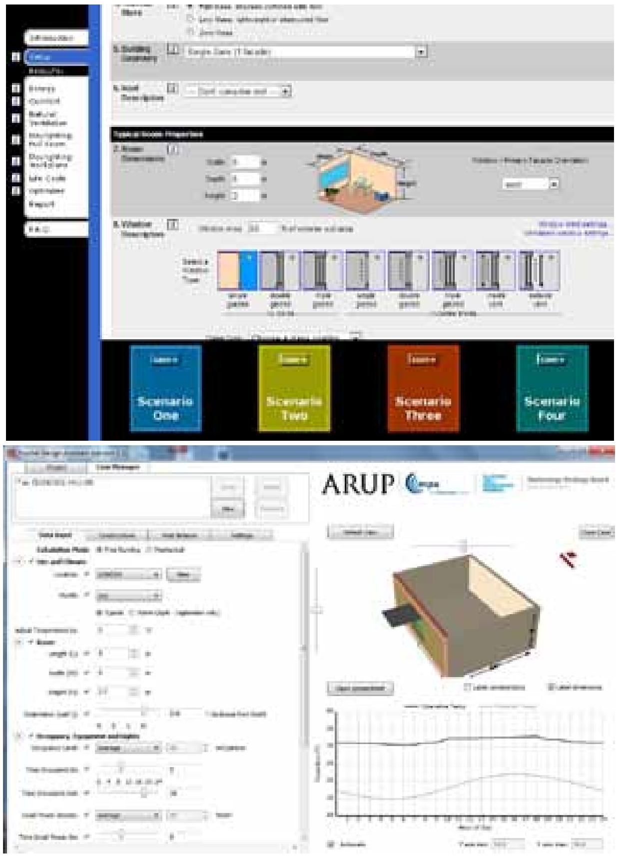


Fig.6-1 MIT design advisor (top) and Arup Passive Design Assistant (bottom) as examples of simple tools for early environmental analysis at building scale. There is no equivalent at urban level

13 MIT design advisor (designadvisor.mit.edu) and Passive Design Assistant by Arup (www.arup.com/Publications/Passive_Design_Assistant.aspx) [last accessed 19.08.2013]

6.2.1. LT Method

The LT Method was conceived as a manual design tool for the estimation of energy consumption in non domestic buildings, with a focus on schools, offices, institutional and health care facilities[14]. It was devised and written by Nick Baker at the Martin Centre for Architectural and Urban Studies, University of Cambridge, and Cambridge Architectural Research Ltd. as part of ARCHISOL programme, coordinated by the Energy Research Group, University of Dublin[15]. The method is based on a mathematical model that contains some thirty parameters which are relevant for the estimation of heating, lighting and cooling. However, since it was developed to assist designers in early sketch designs it only focused on architectural variables. Most parameters, particularly those which are not considered as design variables, have been assigned typical values for each specific building typology. It allows estimates without having to consider aspects that are closer to engineering, such as system specification or details about schedules and occupant behaviour.

The LT method takes into account the concept of passive and non passive zones as it assumes that only the former can take advantage of solar gains, daylight and ventilation. For that reason, the first stage of the calculation procedure consists on the identification of the passive zone, which is normally confined in the building's perimeter and at maximum depth of twice the distance between floor and ceiling. The following steps focus on the basic description of key parameters, basically glazing ratio and orientation. A set of predefined curves can then be used to determine the auxiliary energy that is required for heating, cooling and lighting for each passive and non passive zone and orientation (for non passive zones the glazing ratio is assumed as "zero"). The values obtained from the curves are then entered in the LT worksheet and totalled for the building. Special features such as buffer zones, atriums or the obstruction by surrounding buildings are also introduced at this stage.

The curves have been derived from computer-based mathematical models. The algorithms have considered the balance between ambient energy flows (solar and internal gains, heat loss...) to calculate the supplementary energy that is needed to meet thermal and lighting requirements. Regarding the thermal load, the model takes account of the heat conduction through the envelope and the ventilation heat flow that results from the thermal difference between internal temperature and the monthly external mean values. The monthly gross heating load is then calculated and the contribution of "useful" solar gains and the casual gains from occupants and equipment is detracted. If the resultant internal temperature goes beyond a pre-established temperature, a cooling load is computed and added to the energy taken by a mechanical system to pump in the cool air. Likewise, daylight availability is calculated from the average hourly sky illuminance, daylight factor, and an internal lighting datum value[16]. The need for artificial lighting is obtained from these

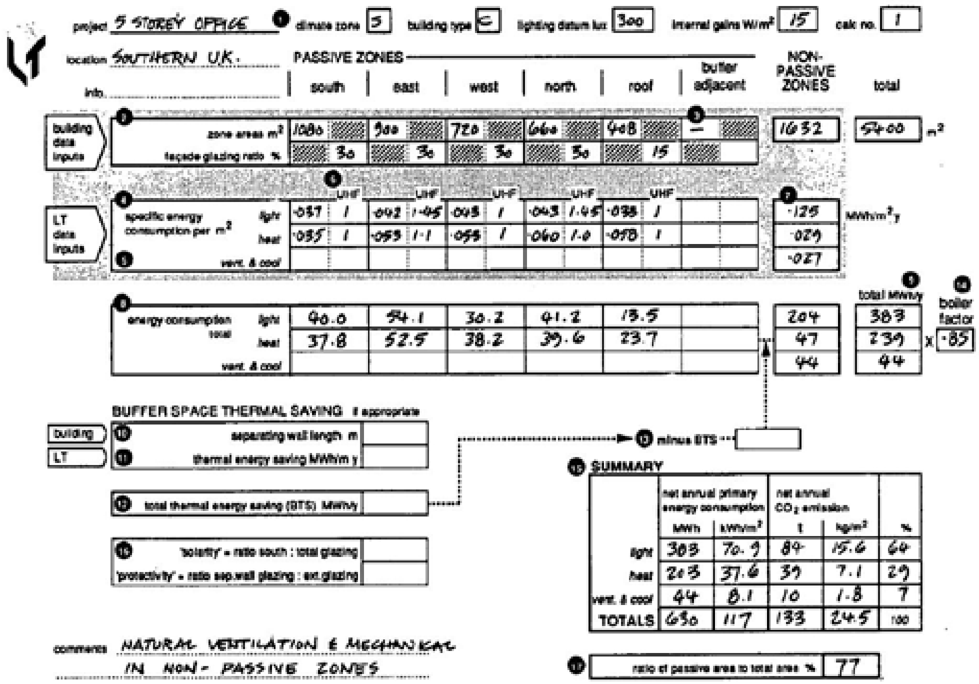


Fig.6-2 The LT worksheet (source: Baker & Steemers, 1995)

14 Baker & Steemers, 2000 p.90
15 Baker & Steemers, 1995
16 Baker & Steemers, 2000 p. 161

three parameters and computed as energy by assuming the luminous efficacy of typical lighting systems. As it can be noted, a great number of assumption have to be taken in order to reduce the input data as much as possible and yet keeping consistent results. The LT method also assumes typical values for constructive elements (U-values), room height (3m), internal reflectance or system efficiency.

Several attempts to adapt the LT model to the urban scale have been made. An early approach was developed jointly between teams at Cambridge and MIT: they tried Digital Elevation Models (DEM) to automatize the introduction of urban parameters and Matlab software to process the algorithms and elaborate the graphic outputs[17]. The use of new information systems to the field of environmental urban studies was an important advance, however it was of limited practically as a design tool since DEM would not be available to test different alternatives and proposals that do not exist (it should be purposely created). A more recent project, namely Climatelite[18], has tackled the issue of early energy assessment in urban design. It incorporates LT model as part of a broader package that has been developed by a Consortium composed by BRE, Cardiff University, Cambridge Architectural Research, Southfacing Services Ltd and Bobby Gilbert & Associates. Climalite aims to calculate the potential performance of urban projects with a graphic interface that resembles CAD software, enabling 2D and basic 3D visualization. Despite certain limitations in the definition of complex geometry, it is relatively user friendly and highly intuitive for architects. Climatelite is suitable for small to medium sized urban developments and for the analysis of detailed urban configurations. However the drawing process is time consuming, every building is drawn up from the footprint of each floor and, although it incorporates certain copy-paste shortcuts, it results practically unmanageable for large urban areas or city-wide analysis.

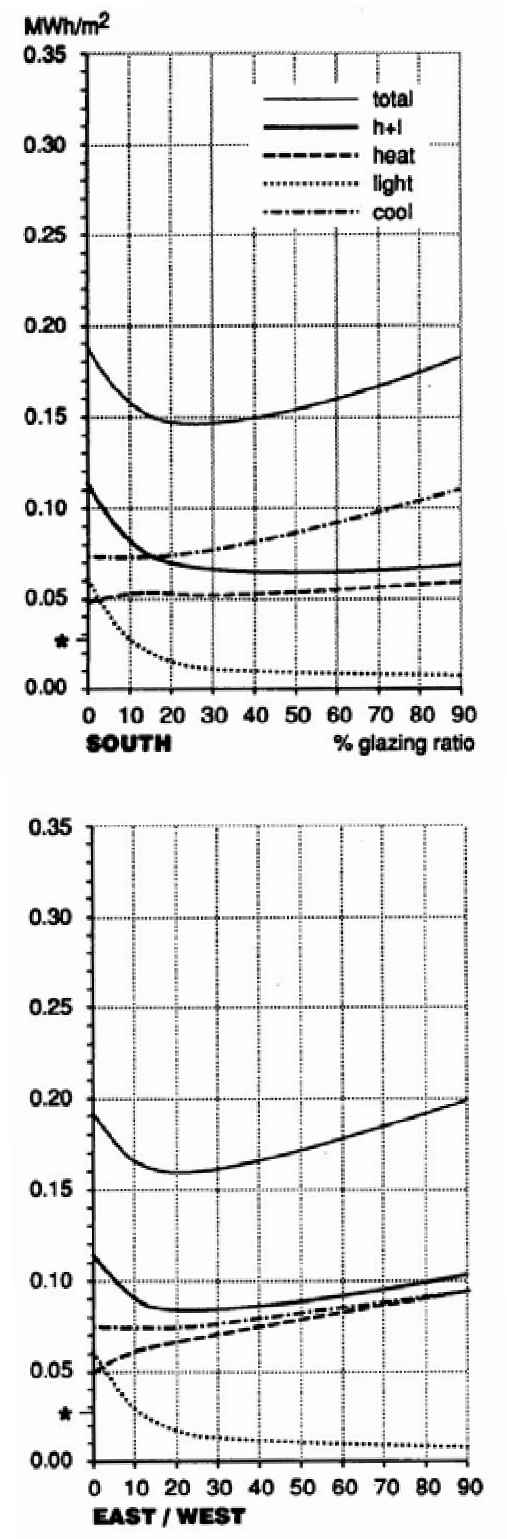


Fig.6-3 LT Curves for offices (type C) and two different orientations (source: Baker & Steemers, 1995)

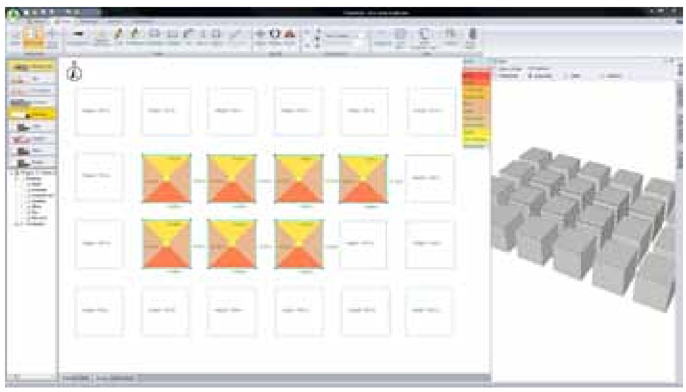


Fig.6-4 Climatelite interface

17 Ratti et al, 2005
18 www.bre.co.uk/page.jsp?id=996 [last accessed 27.12.2012]

6.2.2.Energy Index

The Energy Index[19] was devised by Simos Yannas at the Architectural Association School of Architecture as a design aid for the initial stages of housing projects. It initially consisted on a series of tables with likely effects of design alternatives and the Index calculation method. The tables could be used at the very early phases to discuss targets and options without the need for specific calculations. The index calculation method was intended to minimize the amount of analytic work and test alternative solutions in later stages. A "notional building" is used as a reference for the comparison and assessment of energy measures described in the indicative tables. The standard values of 1990 Building Regulations have been assumed for specifications and ventilation rates. Typical occupancy patterns were assumed whereas dwelling temperature and internal gains were also assigned default parameters. Five sequential steps to improve the energy efficiency of the notional building were subsequently described and assessed in the tables: orientation, double glazed windows with reduced ventilation, night shutters or low-emissivity glazing, increased insulation in roof and walls and mechanical ventilation with heat recovery[20]. The potential savings associated to each step were summarized in two different tables. The first table contained the results for different dwelling types (Detached, Semi-Detached and Terraced) and the second table accounted for the regional variations across different UK climates (table 6-1).

The Index calculation procedure "provides estimates of annual space-heating requirements, fuel costs and CO2 emissions, and an indication of summer overheating"[21]. The heating demand is determined by mathematical functions derived from the results of computer dynamic simulations to account for fluctuations in internal and external variables. The proportion of heating demand that cannot be met by "free" sources (solar and casual gains) is referred to as Auxiliary Heating Fraction (AHF) and it reflects the building's balance between heat gains and losses (Gains-to-Loss ratio, GLR) in combination with its dynamic attributes (heat storage, frequency and intensity of solar gains, ventilation, etc...). A set of pre-calculated values has been compiled and summarized in a table to obtain the Auxiliary Heating Fraction as a function of the building's GLR and window to floor ratio. Several correction factors have been applied to simplify the calculation of useful solar contribution. Heat storage capacity, redundant solar gains, outward reflection or overshadowing are either included in the tables or in the calculation worksheet. Once the AHF is known, the total annual space heating requirement can be calculated by just multiplying it by the gross annual heat loss.

Although the model does not calculate cooling loads, it gives an idea of overheating risk by the assessment of excess gains (redundant solar and internal gains) and its effect on internal temperature. Simulations were performed to

Table.6-1 Energy Index table of regional variations and design specifications (source: Yannas 1994)

Design specification	Heat loss coefficient W/K	W/K m²			PLYMOUTH	LONDON	ABERPORTH CAMBRIDGE	BIRMINGHAM SHEFFIELD	BELFAST NEWCASTLE	GLASGOW	ABERDEEN	MEAN
Reference case												
Randomly oriented 'notional' building of compact form complying with 1990 BRegs	280	2.55	EI	kWh/m²	75	85	95	102	114	115	137	103
			CO_2	kg/m²	23	26	29	31	34	35	41	31
Step 1												
Most windows to south; no overshadowing	280	2.55	EI	kWh/m²	62	74	78	87	96	98	115	87
			CO_2	kg/m²	19	22	23	26	29	29	35	26
Step 2												
As above with all windows double glazed and ventilation rate 0.75 ac/h	210	1.91	EI	kWh/m²	40	48	50	57	63	64	76	57
			CO_2	kg/m²	12	14	15	17	19	19	23	17
Step 3												
All windows with insulated night shutters or low-emissivity double glazing; window area within guidelines	203	1.84	EI	kWh/m²	33	42	43	50	55	56	67	49
			CO_2	kg/m²	10	13	13	15	17	17	20	15
Step 4												
As above and insulation of walls and floor to 0.25 W/m² K	168	1.52	EI	kWh/m²	22	29	30	35	39	39	48	34
			CO_2	kg/m²	7	9	9	10	12	12	14	10
Step 5												
As above and mechanical ventilation with heat recovery (0.5 ac/h)	145	1.24	EI	kWh/m²	15	21	21	25	30	30	36	25
			CO_2	kg/m²	5	6	6	8	9	9	11	8

19 Yannas, 1994

20 Ibid, p.124

21 Ibid, p.128

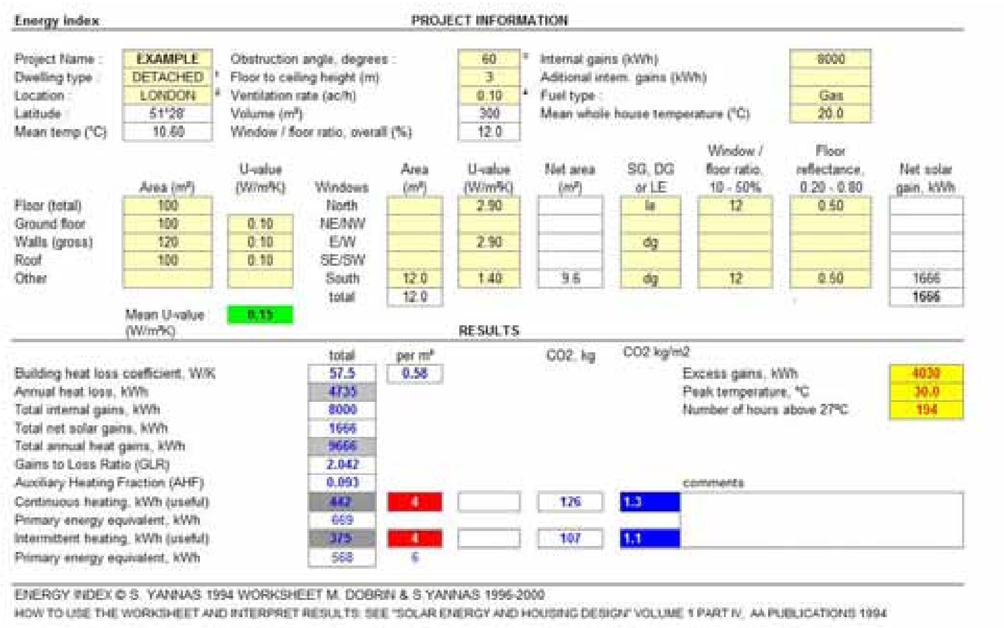


Fig.6-5 Energy Index spreadsheet (source: Dobrin & Yannas, 1996-2000)

establish correlation patterns between the yearly total excess gains and overheating frequency (when internal temperature rises above 27ºC). The occupants' adaptive behaviour was considered in the simulations by assuming that they would open the windows to introduce fresh air well before internal temperatures reached 27ºC, so that part of the excess gains could be dissipated. A graph was produced with the results from the simulations thus peak temperature and the frequency of hours above 27ºC can be obtained in a simple step and having excess gains as the only input parameter.

The Energy Index method was devised, like the LT model, as a comparative design tool rather than a model to simulate final performance. A designer can use EI to ascertain the potential effect of multiple variations in different design parameters without having to repeat the whole calculation process over and over. A computerized version of the spreadsheet tool has allowed for even quicker evaluation[22]. In few seconds, the heating load for different window sizes, orientation or internal design temperature can be estimated. Its reliability has been tested by performing parametric studies of real case studies and comparing the results against powerful thermodynamic simulators. A close correspondence when the Heat Loss Coefficient of the assessed building is within an intermediate range (0.5 and 2 W/m²K approximately) has been revealed. For lower and higher values, the Energy Index tends to overestimate the heating load in comparison with outputs from thermodynamic models[23]

6.2.3.Learning outcomes

Although the number of available building energy tools has notably increased during the last years (some 393 tools have been compiled in a directory created by the U.S. Department of Energy[24]) most of them require a considerable amount of input parameters that may be of limited interest at early design stages. Moreover, the fundamental nature of planning requires a different set of tools that account for building specifications from a more general, top down approach. Conventional energy simulators, which are based on the thermodynamic assessment of detailed thermal zones, are not suitable to perform simulations at urban scale. The amount of work and computing time grows exponentially when the interaction between buildings is considered at the same level of detail. The precedents of LT model and Energy Index demonstrate the advantages of simplification in order to develop manageable environmental design supporting tools. Simpler models produce reasonable results from relatively few input parameters and some predefined assumptions. Urban morphological studies could benefit from a tool that provides information about energy performance of different typologies. If the analysis is circumscribed to variables that are familiar to urbanists, the evaluation becomes simpler and energy aspects could be more easily integrated in planning decisions.

22 Dobrin & Yannas, 2000

23 Comparisons between EDSL TAS and Energy Index were done at Architectural Association School of Architecture, MArch/ MSc Sustainable Environmental Design (www.aaschool.ac.uk/ee)

24 apps1.eere.energy.gov/buildings/tools_directory/ [last accessed 27.12.2012]

6.3. Some notes about urban models

6.3.1.Origins

According to Echenique[25] a model is "a representation of reality, in which the representation is made by the expression of certain relevant characteristics of the observed reality and where the reality consists of the objects or systems that exist, have existed or may exist" To that, Batty added the "manipulation of represented phenomena" as part of the definition and simulation as "the process to characterize its implementation"[26].

The origins of urban modeling can be traced in two related disciplines: transport studies and urban structure[27]. During the 1940s and 1950s the increase of car ownership started to congest the American cities so that early transport studies were carried out. Part of these studies involved the predictions of future trip generation and spatial distribution. A theory of "gravity models" was based on analogies with gravitational forces, where trips were proportional to the "mass" of the origin and density and inversely proportional to the distances. The early studies did not pay attention to land use aspects until the 1960s. The other approach was trying to build theoretical models of urban structures. The idea was based on the theory of price of land according to distance to the market that was devised by von Thunen in 1826[28]. He suggested that the sum of the cost of an agricultural land and the cost of transporting the product from that land to the market was a constant value. This was further elaborated in the 1960s to produce land use modeling.[29]

Urban modeling was part of a wider scientific revolution in social sciences in which the view turned to modern physics and computers, hoping to make use of the rigor and quality of the former and the *speed and mechanical accuracy* [30]of the latter. Numerous urban models were built during the 1960s, most of them were funded by metropolitan planning agencies (Boston, Baltimore, Connecticut, Pittsburg[31], New York) . These were ad hoc models to represent those particular cities. Although they brought good learning about their potential and limitations, they did not succeed and they were abandoned at the turn of the decade. According to Batty[32], the following aspects made difficult the implementation of these pioneer experiments:

- An over-confidence in the capacity of models in addressing the high complexity of the modern metropolis. Modelers failed to foresee the limitations of their models.
- Difficult testing. As in other social sciences, it was difficult to hold all variables but one to track the effect of its variations.

In the 1970s, the topic was taken up again, mainly in the UK where the solid structure of the planning system and academic research, together with the move to a systemic approach to planning created a favorable scenario for urban research and the development of new tools to explore, understand and predict urban problems. Unlike the first generation, models were, in this case, being investigated at Universities (Manchester, Reading, Cambridge...). The first consequence was that the extrapolation of the model to different situations and locations became more important than accuracy.

6.3.2. Models and theory

There is a general consensus throughout generations of urban models about the need of a solid theory as prior requirement. A mere description of events would have not any relevance if it is not referred to a broader theoretical framework. All description of reality implies interpretation and assumption[33]. Theory is an abstraction of reality where information (observation) and assumptions (inferences) are combined. Knowledge can then be built upon iterative testing of the validity of those assumptions to increase the proportion of information and develop further inferences. The scientific method of observation-theory-testing-observation is applied to urban models, where the laboratory has become the computer. The model is a representation with a pre-defined purpose and therefore the selection of information and the assumptions to build the model depend on the type of questions that are explored. Only the facts that are useful need to be collected.

Hesse[34] describes three types of theories according to their level of assumptions and predictive powers, which are inversely proportional: formal, conceptual and material theories:

- **Formal**. All relations are supposedly known and, therefore, they bring more accurate representations of reality expressed in mathematical terms. They are weakly predictive but represent the necessary starting point for any model. For instance, a building which is represented in terms of budget, cost and amount of material is a formal model.
- **Conceptual**. Relations are imagined and established by rather arbitraries analogies as they do not part from a clear fact or empirical analogy, which are then tested. They are highly predictive since they are free from many constrains, but the level of inaccuracy can be also high. The atomic and DNA structures were conceptual models.

25 Echenique, 1972
26 Batty, 2010
27 Batty, 1976
28 Ibid.
29 A simple software programme to run and explore von Thunen's theory was done by Echenique and it is available at: www.casa.ucl.ac.uk
30 Lowry, 1965
31 For Pittsburg, see Lowry, 1963
32 Batty, M. (1976)

33 Hesse quoted by Echenique 1972 p.164
34 Idid. p. 166

- **Material**. They are strongly predictive and based on empirical data. The basic assumption is that "if things have some similar attributes they will have other similar attributes"[35] Then a validated theory that explains some phenomena can be used to explain in equivalent terms other phenomena. Traffic models based on gravity or energy flows based on electric circuits are two examples

6.3.3. Error and complexity in models

It can be argued that the discussion about sustainable urbanism has been dominated by two main diverging perspectives: rhetoric and pragmatic. The former uses language and logical reasoning to concatenate causes and effects. The proponents are rather reluctant to rely on engineered solutions, which are felt as too deterministic and, to some extent, detrimental to human discernment and judgment. Pragmatists, in contrast, believe in the empirical evidence and are primarily concerned with mathematics and scientific methods. They use systemic analogies and create models to test their hypothesis, as objectively as possible. The theoretical argument is confined to the setting of problems while the search for solutions is driven by facts, observations and trial-error experiments. The discussion between theorists and practitioners has some parallels in the past. The systemic approach that emerged in the fifties and sixties was severely confronted by "conventional" planners of the time and, more recently, the use of mathematical models has been defined as a "fantastic trip to Wonderland"[36]. One of the most influential and critical articles regarding the systemic approach to planning was however less reactionary. Douglas Lee's Requiem for Large-Scale Models[37] put an end to the early systemic approach in 1973 and planning disengaged from early experimental models. However, neither it was the end of urban modelling[38], nor did the author intend to make a general denial about the validity of quantitative analysis in planning[39]. He rather criticised the flaws that were observed in the early experiments while proposing some guidelines to ensure that the potential contribution of models to planning could be effectively delivered[40]. Those guidelines are summarized as follows:

- The most important attribute of a model should be "transparency". Big "black box" models are to be avoided as they do not allow a direct investigation of the points of disagreement.
- The balance between theoretical basis, objectivity and intuition should be a major aim. Overemphasis on any of those aspects may lead to loss of contact with reality, empty-headed empiricism or erratic problem solving.

35 Ibid. p166
36 Klosterman, 1994
37 Lee, 1973
38 Batty, 2004
39 Lee, 1994
40 Lee, 1973 p.176

- Start from the clear definition of the problem to be addressed and the selection of the most adequate method to solve it. The opposite of this was the application of methods just because they needed to be tested or because were novel.
- Build only very simple models. The modeller has the capacity to discern what to disregard in building the model. Complex models do not work better and they cannot be understood by others.

Two of the most important objectives that were considered in the elaboration of the urban energy model that is described in this chapter were simplicity and legibility. The model had to be manageable, require a reasonable effort and dedication, and it had to refer to aspects which were familiar to planners and policymakers. For this reason, much work has been dedicated to the extrapolation and adaptation of knowledge from buildings to the urban scale. The most important target was to obtain meaningful outputs. Even though the accuracy was limited by the assumptions, any deviations that may appear in the results had to be easily traced, so that the analyst could interpret whether the model fits the purpose for that specific assessment.

Simplicity has further advantages and it does not necessarily make models more liable to errors. As Alonso[41] had described, errors in a model can be of two types: error of measurement, derived from data inaccuracy, and error of specification, which responds to the inherent limitations of models to represent the reality. Specification errors can be counteracted by adding more variables and chains of models, which increases the model complexity. However, if the number of variables increases, the potential error due to data inaccuracy will also tend to accumulate. It has been argued, in different fields, that the complexity of a model can, indeed, compromise its precision since errors are magnified with almost every arithmetical computation[42]. Assuming the model is well structured and the specification is well calibrated, the precision of the model could be improved by adding more parameters. However, although structural uncertainty tends to decrease, parameter uncertainty increases with greater complexity (fig. 6-4 A). Moreover, if the model structure is poorly calibrated, the addition of parameters does not attenuate the uncertainty but it enhances it (fig. 6-4 B).

Both LT and Energy Index are simplified models that use a limited amount of input parameters while having a sound structure. The development of Urban Energy Index (UEI) follows a similar concept. Complexity is moderated in order to facilitate operability and the control over assumptions and errors. In the transition from building to urban scale two essential prerequisites were taken: first, the input parameters had to be limited and familiar for urban professionals and,

41 Alonso, 1968
42 Willumsen, 1985 Silberstein, 2006

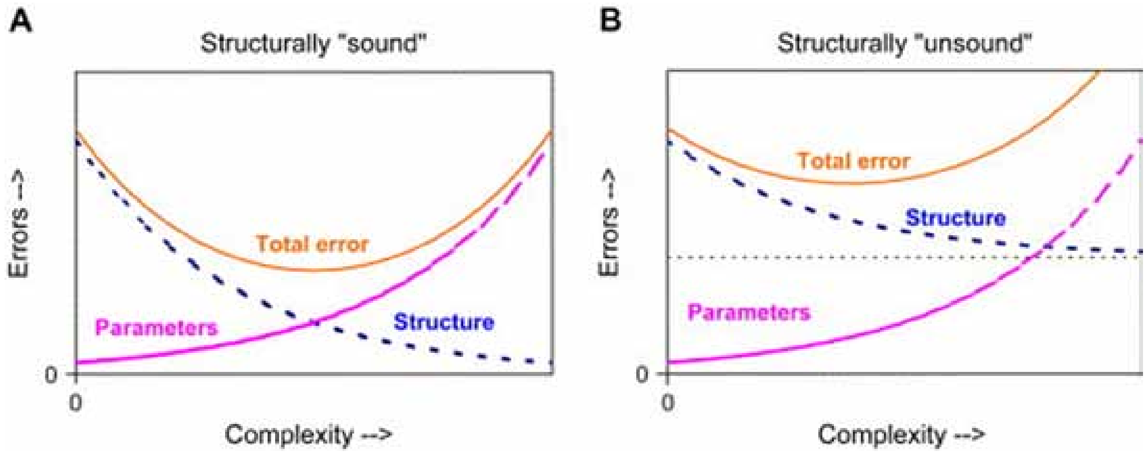


Fig.6-6 Notional components of model prediction error. Left: Structurally sound model, minimum error with an optimum combination of parameters and complexity. Right: Structurally unsound model, higher prediction error which increases as complexity is added (Silberstein, 2006)

second, the characterization of the urban fabric by these parameters had to be univocal and systematic. The inherent heterogeneity of the city was an important issue that had to be addressed. Taking account of every singular typological variation in large areas would be unmanageable and it could compromise the legibility of the model. Building variables can vary enormously from one building to another: windows position and size, shutters, envelope materials, height or occupancy patterns are relevant factors for determining energy demand but they are difficult to quantify and, in the case of behavioral patterns, they present a high level of uncertainty. Although fieldwork and surveys can be undertaken to measure windows and collect information about materials and occupants, this is expensive and time consuming and it lies in a different level of urban analysis. Some models use stochastic formulas to depict variations in building parameters. Random values within a range are assigned to occupation or ventilation to portray occupants' behavior[43]. A different strategy consists on deterministic allocation of default values, which ensures a clearer discernment of what is going on inside the model (i.e. values are known).Urban Energy Index assigns default values to many building variables. However, these attributes can be changed altogether and they are always transparent to the analyst.

6.4 Parameter Values

6.4.1. The connection with classic urban morphology

The classical approaches to the study of urban form have been broadly analyzed in Chapter 2. The outcomes from these theories will feed the theoretical basis of the model and will be applied in the formulation of its structure. The three main schools of morphology in the twentieth century, Italian, French and English, had common points in their approach to the physical domain. They criticized macroscopic analysis because it disregarded the smaller scale at which the city had been actually produced and experienced[44]. The concept of type is the link between building scale and city scale. The urban types were defined by the combination of built structures and the related open spaces. Within this common framework, each author elaborated specific theories. Muratori considered the urban tissue as a superimposition of three logical systems: roads, plot subdivisions and buildings.[45] Similarly, the English School based the analysis of the town plan on the identification of three layers: streets, lots and buildings.[46] The Italian School was concerned with the aggregation of built objects in four hierarchical scales: building, block, city and region, with especial attention to buildings and their adjacent space ("edilizia"[47]). The city was understood mainly as a process rather than as static entity. Panerai proposed a reductive view of the city to differentiate its various logic composing systems. This reduction could then be disentangled to compare the findings against reality[48]. He therefore implied a detachment of built space from the social space that gave meaning to it, thus impregnating the morphological analysis with a "false" objectivity[49]. In the same line, Alexander had pointed out, in his thesis "Notes on the Synthesis of Form",[50] the relevance of mathematical logic structures in formal analysis to rule out any preconceived idea. Once the physical elements were released from their symbolic and functional attributes, the description of the urban fabric could focus on formal aspects.

43 Robinson et al, 2011

44 Moudon, 1994
45 Panerai et al, 2004 p.170
46 Moudon, 1997
47 Caniggia & Maffei, 1995
48 Panerai et al, 1983
49 Ibid
50 Alexander, 1974

6.4.1.1. Morphology beyond the physical form: Systematic and characteristic order

The study of the processes that shaped the city have become, at least, as important as the analysis of its physical structure. A differentiation between immaterial relations and physical residues is present from Muratori to Alexander and Lynch. Current approaches to urban morphology have engaged the investigation of meta-spatial attributes that are relevant to urban performance. Those properties are to be retained across alternative means of representation that aim to simplify the spatial complexity while keeping the integrity of key performance features. The morphogenesis of cities was extensively discussed by Marshall in "Cities, Design & Evolution"[51]. He proposed the reduction of the city into its component units[52] in a progressive sequence: from basic structural differentiation of the parts of the city (centre and suburbs) to the smallest subdivision, in which high resolution analysis is possible. He concluded by defining the basic units at the smallest level, which closely coincide with those formulated in previous theories: buildings, plots and routes. Buildings plug into plots, and plots into routes, defining an specific kind of order. Interestingly, he differentiates between two different types of order: **systematic order and characteristic order**. The former can be found in planned cities: the rules that originally determined how buildings and streets had to be built are easily traced in the urban fabric. This was the case for many colonial cities, such as the Spanish grid or French Bastides. Characteristic order refers to identifiable logics or patterns that emerge in the analysis of the urban fabric which did not result from deterministic decisions but from somehow spontaneous city making process. It is typical in cities that grew organically while following unwritten logics. The irregular streets on medieval villages are an example of characteristic order. Their physical layout arises from the need for connection and to maximize property within enclosed walls. They do not respond to a predefined plan. However, the similarities can be noticed across different cities, this is due to the underlying characteristic order. Characteristic order is a key concept that will be explored and adapted for the formulation of the Urban Energy Index.

6.4.1.2.Typological and parametric morphology: density

Classic morphological studies were more concerned on qualitative typological analysis than on the quantitative definition of urban form. They were primarily a reaction against functional planning and the disregard of historic city centers. The identification of references would enable a natural continuity in the city making process. These references could be found either in traditional architecture (Muratori) or in the immediate context, studying the topography and landscape (Quaroni). In planning practice, quantitative standards had been a common instrument since the second half of the nineteenth century, when the industrial revolution brought about massive migrations and the earliest problems of urban overcrowding. During the twentieth century, **density** was probably the most widely used indicator for both describing structural problems and regulating the growth of cities. Despite being a numeral dimension, the notion of density has transcended mere quantification as it rarely remained neutral. Density has acquired different meanings over decades. At the end of the nineteenth century, overcrowding was so acute that it became a generalized social problem. The first By-Laws and Town Planning Acts were enacted to establish maximum

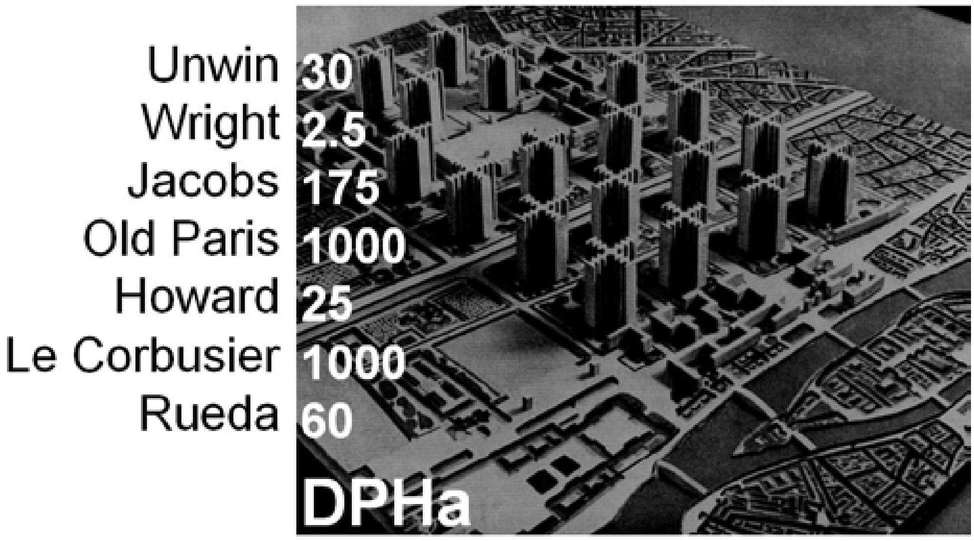


Fig.6-7 Different density reference values, existing or proposed

51 Marshall, 2009
52 Ibid, p.40

Fig.6-8 Different urban typologies for an FSI=1 m²/m² (Urban Task Force, 1999)

limits to density. Raymond Unwyn proposed a limitation of 30 dwelling per hectare (dpha)[53] and Howard's garden city prescribed 25dpha[54]. By the mid of the twentieth century, modern planners combined high density with hygienic concepts. They proposed high-rise buildings floating on an open urban context. Their proposals would nevertheless be stigmatized as too mechanistic and unsuitable to satisfy the expectations of a rapidly raising middle class. The bulk of urban dwellers in Europe and USA (especially) were unimpressed by modernist imagery as they preferred the suburban detached family house and garden lifestyle.

The notion of density was subsequently reversed, from a situation of overcrowding to its opposite: urban sprawl and low density seen became a threat to urbanity. The alternative after the failure of modern planning was to prescribe a minimum density so as to ensure the feasibility of services, a sense of urbanity and a more sustainable use of land. Jane Jacobs, who was one of the most influential figures in Anglo-Saxon post-modern planning, suggested 175 dwellings per hectare (dpha) as a reference to achieve urban vitality.[55]In later years, the prescription of minimum density has become a fundamental principle in sustainable development theory. Improvements in transport and energy use are alleged benefits of dense urban fabrics, while greater social interaction and better livability are often alluded to as qualitative outputs from concentration and compactness.

It has been frequently argued that density alone is a poor indicator that hardly reflects the spatial properties of urban fabric.[56] Indeed, the term is ambiguous as there is no universal measure of density. A broad range of variables are used to define it, some measures are widely established while others are circumscribed to specific contexts. Demographic or social studies usually refer to people density whereas in planning, building density is a more practical notion as it is less dynamic and fluctuating. The notion of building density counteracts the duality between residential (where people sleep) and jobs density (where people work), although information about these two parameters will be also useful to understand urban phenomena, such as daily travel flows. How the study-area is delimited will also determine the computation of density. If greenfield land and non-urbanized areas are included, the resulting density will be lower than for net density, which excludes non-urbanized areas from the computation. Regional density is normally calculated as gross density, this is, with non-urbanized territories being included. In contrast, intra-urban zones, such as neighborhoods or blocks, can refer both to net or gross density. In addition, the perception of density also depends on the context. The same value can be accepted or rejected by residents with a different urban experience. Residents of Hong Kong and London may have developed a different "tolerance" to density. What the Londoner perceives as unbearably overcrowded may result acceptable for Hong-Kong people.

To overcome the ambiguity of population density and the bias of residential density, the Floor Space Index (FSI) was proposed in 1948 as a common measure in Europe[57]. It had been previously used in the United Kingdom and its equivalent can be found in North American legislation (Floor Area Ratio). The FSI indicates the total floor area that is built over a delimited region (a plot, block or city zone) per unit area. It does not refer to any specific building type and it is less fluctuant than population parameters. However, a number of different urban typologies are defined with the same FSI. Variations in urban form are simply determined on how the construction is arranged in the plot. A 20 storied tower block surrounded by open space, four rows of terraces and a peripheral alignment around a central square can all deliver FSI values around 1m²/m² as illustrated by fig. 6-8

53 Unwyn, 1909
54 Howard, 1898
55 Jacobs, 1961
56 Berghauser Pont & Haupt, 2010
57 Ibid

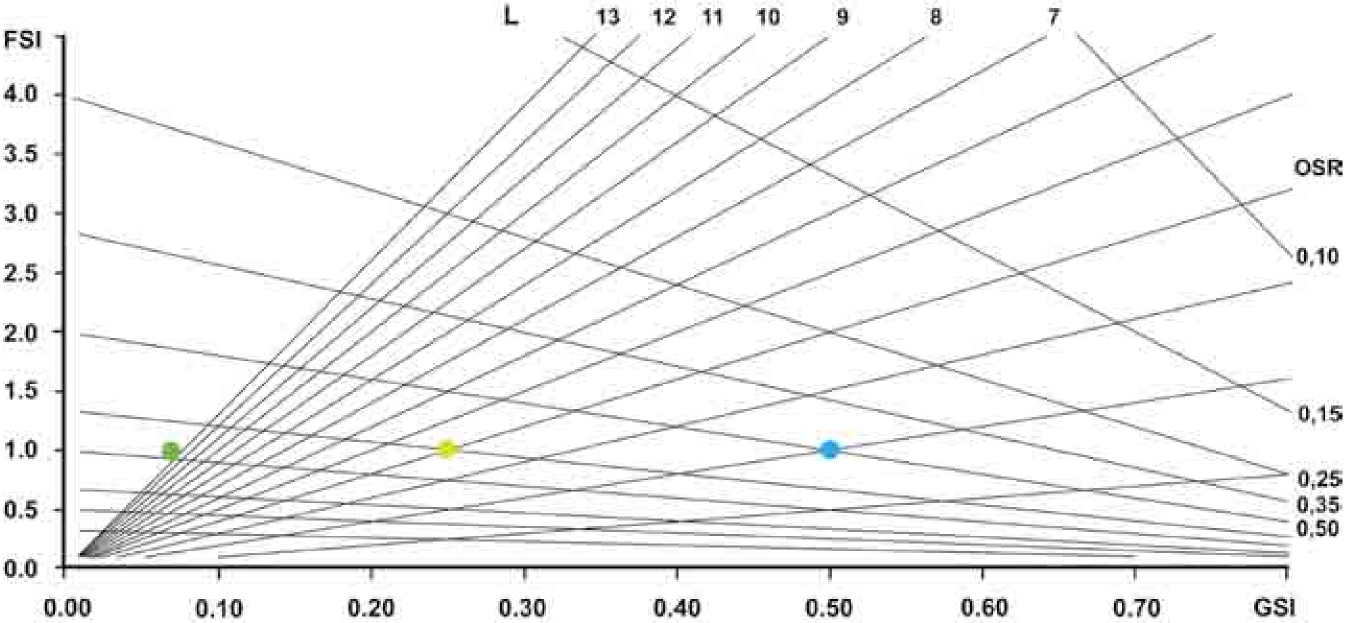


Fig.6-9 Spacemate diagram, the dots represent the three urban samples in fig.6-8. FSI: Floor Space Index, GSI: Ground Space Index, OSR: Open Space Ratio, L: Number of floors. Dots:Green: tower block, Yellow: square and built perimeter, Blue: terrace. (after Berghauser Pont & Haupt, 2010)

The measure of land coverage is a complementary indicator that gives, together with the FSI, a univocal definition of urban form. It expresses the proportion of land that is occupied by buildings. It has been extensively used in planning since Cerdá's plan for Barcelona (a plot coverage of 50% had been prescribed). Every combination of FSI and coverage can be related to a specific urban typology, limiting the range of possible variations. If these two values are known, it is easy to derive other parameters, such as the average building height (FSI/coverage) or the proportion of open space per built area (1-coverage/FSI). A recent research carried has gone one step further and it proposed a "multi-variable definition of density" based on FSI, coverage (referred to as Ground Space Index, GSI) and a third parameter, Network Density (N)[58]. The authors argued that the combination of the three variables was specific enough to determine urban types, as well as simple enough to manage the data comfortably. In addition, a set of tools was elaborated to represent these values in what has been named "**spacemate**" diagrams, which allow a clearer visualization and systematic data management.

6.4.3. Hypothesis

Urban Energy Index uses FSI and GSI, together with compactness, as main input parameters. The research hypothesis is based on the assumption that the combination of these two variables together with a notion of the prevailing orientation and the compactness of the urban fabric contain enough information to make meaningful estimates of energy performance on large urban areas. The postulation of density, represented by FSI and GSI, meets the initial objectives of simplicity and familiarity to planners. Before continuing with a detailed explanation of the model development, a definition of every parameter included in the calculations is provided so as to clarify their meaning, origin and interpretation:

6.4.4 Basic Parameters

According to the hypothesis, three parameters contain most of the necessary information to perform the energy assessment on dense urban areas:

Floor Space Index (FSI)

It represents the gross built up area per unit area. It includes all uses and floors above ground level, whose area is divided by the land area. It is measured in m²/m² and it is a typical descriptor of density in urban planning documents.

$$\mathbf{FSI = TFA / A}$$

FSI: Floor Space Index (m²/m²)

TFA: Total Gross Floor Area (m²)

A: Gross Area of the land unit (m²)

Coverage or Ground Space Index (GSI)

It indicates the proportion of land that is occupied by buildings. In this indicator, only the building' footprint is computed and then divided by the total area of land.

$$\mathbf{GSI = GFA / A}$$

GSI: Ground Space Index (m²/m²)

GFA: Total Ground Floor Area of all buildings (m²)

A: Gross Area of the land unit (m²)

58 Berghauser Pont & Haupt, 2010

Compactness Ratio (Comp)

This parameter is not uncommon in urban planning but it is important regarding the energy performance of buildings. It is defined as the proportion of external envelope in relation to the floor area. A similar variable is used at building scale to illustrate the degree of exposure of the internal spaces to the external environment. A large envelope to floor proportion would enhance heat flow and, depending on climate and materials, penalize energy consumption greatly.

$$\textbf{Comp = Env / TFA}$$

Comp: Compactness Ratio (m^2/m^2)

Env: Total External Envelope Area (m^2)

TFA: Total Gross Floor Area (m^2)

6.4.5. Default Parameters[59]

Other parameters included in the model are initially assigned default values in order to facilitate quick estimates. They can however be altered if the influence of one particular variable is to be analyzed or specific data has been collected. They have been considered as secondary parameters for various reasons:

- The margin of error in the measurement of the parameter from real data is large and of relative influence in the model's performance, which makes the use of typical values a better option
- They refer to specifications at building scale rather than to actual urban parameters. For instance, if the focus of the study is on urban typologies the specific characteristics of window glazing may be redundant.
- They are of minor interest in formal analysis because they do not describe spatial attributes. The color or the materials that compose the façades are not directly related to urban morphology. These and other elements, which may have some impact in environmental behavior but are not determinant factors, will be also assigned default values.

The attributes which are assigned default values are:

Orientation Ratio (Or)

Although orientation may play a limited role in dense urban areas, due to the high obstruction angle created by buildings, its study is still relevant for solar studies. The orientation ratio refers to the proportion of elevations that are orientated in each direction. The distribution of prevailing orientations can be graphically illustrated by a radar chart, in which orientations are categorized in regular intervals (fig. 6-10). The definition of Orientation Ratio assumes that the urban fabric tends to be relatively orthogonal, especially when it is dense or moderately dense. This assumption has been derived from pthe previous analysis of 28 urban samples in five European cities. It implies that there are two main perpendicular axes along which elevations are orientated. From these two axes, the main one is defined as the closest to the North and the secondary orientation is defined as orthogonal to the former. The Orientation Ratio is then defined as the proportion between the area of the elevations oriented to the main axis to the elevations oriented to the secondary axis. The Orientation Ratio also provides a sense of typological arrangement. A regular grid like Barcelona's Eixample has an Orientation Ratio close to one, because blocks are rather quadrangular. In contrast, long and shallow linear bocks will probably give a value well above or below one, as a result of the little exposure of one of their sides. If the value of Orientation Ratio is unknown or it cannot be calculated, a ratio of 1 can be selected as default and then sensitivity studies could be performed to get an idea about the influence of orientation.

If the main orientation is the N-S axis, the Orientation Ratio would be obtained as:

$$\textbf{Or} = \sum(\textbf{Aelev N-S}) / \sum(\textbf{Aelev E-W})$$

Or: Orientation Ratio

Aelev N-S: Elevation Area oriented to the Northern-Southern quadrants (m^2)

Aelev E-W: Elevation Area oriented to the Eastern-Western quadrants (m^2)

Typical Floor Height (fh)

Floor height is used to calculate the average building height in meters. The proportion FSI/GSI will provide an estimate for the average number of floors in the whole study area. The mean building height can then be obtained by multiplying that number for the typical floor height. If this value is not known and it cannot be measured, it can be assumed as around 3 meters.

Glazing Ratio (Gr)

Although the aim of the model is not to evaluate building characteristics but the urban form, it is still necessary to portray the effect of openings, so that the energy balance can be calculated. The Glazing Ratio is defined as the proportion of façade that is taken by windows and glazed elements. In building assessments, windows have to be specified in each orientation. In urban assessments however, it can be assumed that the distribution of openings is homogeneous in all façades.

$$\textbf{Gr} = \sum \textbf{Aglass} / \sum\textbf{Aglass+Aopaque}$$

Gr: Glazing Ratio

Aglass: Glazed openings in all elevations (m^2)

Aopaque: Opaque openings in all elevations (m^2)

59 See appendix for data specifications used in the model

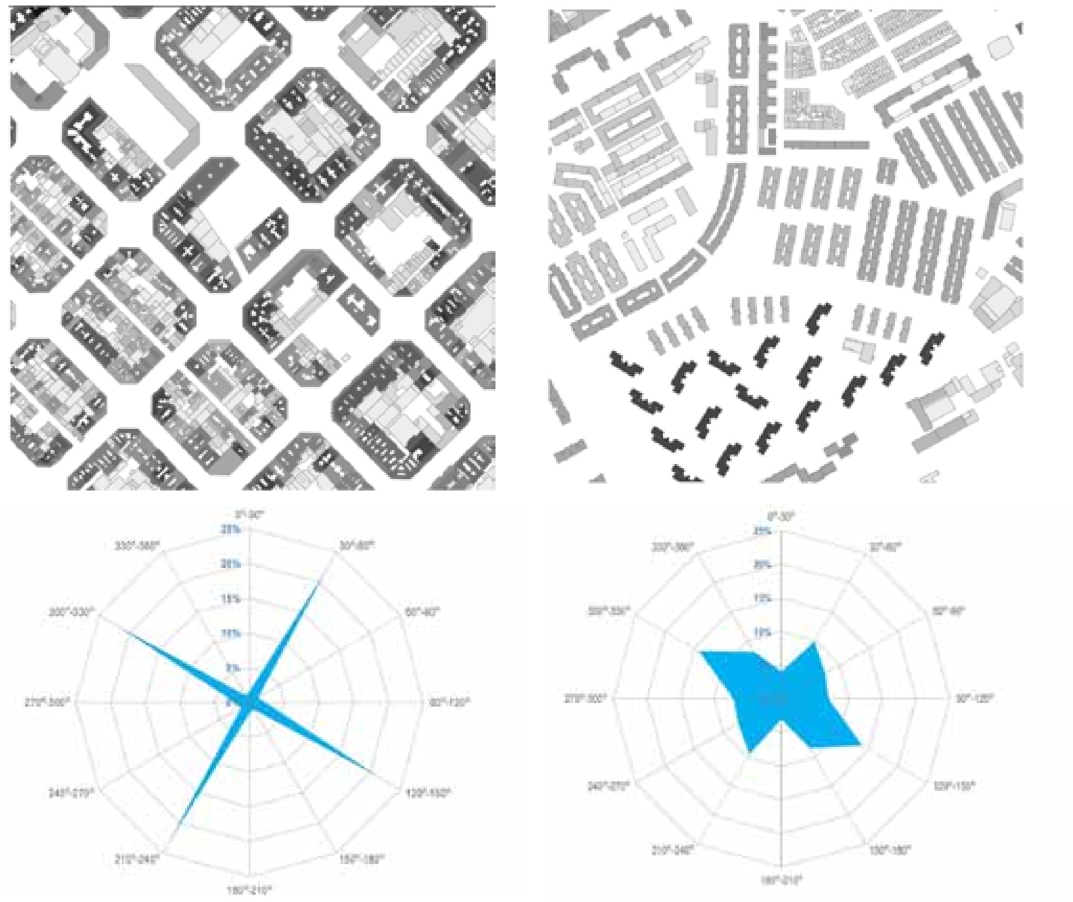


Fig.6-10 Orientation rose for Eixample in Barcelona (left) and Simancas in Madrid (right). In the former, the main axis corresponds to NE-SW and the secondary to NE-SW with the indicated angles. Since the fabric is predominantly orthogonal the Orientation Ratio is close to one. The same axis would be selected in Madrid, but a different Orientation Ratio would be obtained as the secondary axis is greater than the primary axis.

Construction type (Ct)

The type of materials and constructive systems can be inferred from the age of the buildings in that area of the city. Buildings from a similar period may show small variations in terms of insulation or window type. A reference value is assigned by default, which corresponds to typical specifications in buildings from the ninety nineties in United Kingdom. This parameter can be easily modified, for instance to simulate an old fabric or a new low carbon development that proposes highly insulated buildings. The level of insulation will have a significant effect in the energy studies. The influence of form in heating and cooling loads will tend to diminish in highly insulated buildings.

Thermal capacity (Tc)

The thermal storage capacity indicates the potential to accumulate excessive heat and to release it afterwards. It will be used to take account of dynamic heat flows by its correlation with the utilization factor, which is the ratio of useful solar heat gains to the total solar gains. Different correlations are found for light, heavy and very heavy buildings. For simplified energy models the use of these coefficients gives an approximate notion of the effect of thermal capacity. Formulas of utilization factor developed by Yohanis and Norton have been used in the model[60].

Albedo(ρ)

The albedo represents the reflectance of external surfaces and it is used to calculate reflected component of solar radiation and daylight factor. A high albedo typically corresponds to a clear surface and it means a large solar reflectance. A default value of 0.2 is used as it is typical in urban surfaces[61]

60 Yohanis & Norton, 1999
61 Oke, 1987

6.4.6 Context Parameters

Three important aspects are required to define the location and specific context of the study area:

Climate

Five climatic zones have been added to the model so far. They represent a range of locations across Europe. Weather data contains hourly values for temperature, solar radiation, humidity and wind speed. The climate for the study area will be selected from a roll-down menu and all data are available for consultation. Other climates can be added, provided that datasets were obtained for the aforementioned parameters.

Latitude

The sun position is updated for every hour when the latitude is introduced. This is relevant for the calculation of radiation intensity and obstruction.

Main orientation axis, deviation from North

As mentioned before, the prevailing orientation axis is calculated for the urban sample. Typically the second dominant orientation is tilted ninety degrees from the main axis. Knowing the main orientation's deviation from North allows the use of solar geometry to compute the solar gains on each façade, taking into account the obstruction caused by surrounding buildings.

Land Use Breakdown and Building Types

Optionally, information about Land Use can be also supplied to the model. Five categories of land use have been defined: residential, retail, industrial, facilities and offices. They contain general specifications and assumptions on occupancy, schedules, lighting, etc... Each land use intends to reflect the main characteristics of those building types. The compromise between simplicity and accuracy has limited the definition of building types only to a loose notion. A comprehensive Land Use classification would increase the complexity of the model substantially and the identification of trends would become more difficult.

6.5. The Mathematical Model

The strategy devised for the urban energy model consists of a fundamental hypothesis and two main calculation stages.

Hypothesis:

The average energy demand for heating, lighting and cooling from buildings in a moderately dense, regular or irregular, urban area is analogous to the demand of a notional regular grid which has retained, from the original urban fabric, information of the following parameters:

- Built footprint (GFA)
- Total built up area (TFA)
- Envelope's Area (Env)
- Buildings' perimeter (P)
- Proportion of façades facing the main orientation quadrant to façades facing secondary orientation quadrant (Pn-s/Pe-w)
- Average obstruction angle in two main axes (θ)
- Built volume (V)
- Average building height (h)
- Average number of storeys (f)
- Glazing ratio (Gr)
- Construction type (Ct)

Stage 1: The first step of the calculation process consists on the transformation of the real urban fabric into a characteristic notional grid that preserves all the aforementioned parameters. This is done through a series of predefined algorithms that were theoretically inferred and validated with real samples and the aid of GIS.

Stage 2: The second step consists on the calculation of the energy demand for heating, cooling and lighting, of the notional grid. For this process, a simplified energy model is used and adapted to urban characteristics. The calculation procedure contains fourteen steps which were initially embedded into a spreadsheet for ease and speed. A GIS application has been also produced. So far, the GIS model is based on results from regression analysis performed over the validation of the spreadsheet tool. This will be discussed in more detail in following sections

6.5.1. Notional Characteristic Grid

The characteristic notional fabric contains the urban spatial parameters that influence energy performance. It allows comparative analysis of urban energy behavior without complex modeling. The transformation from the irregular, heterogeneous fabric into an analogous regular structure simplifies the calculation of average loads. Instead of one-by-one estimates which are eventually averaged, this strategy takes a top-down approach. It starts by averaging the geometrical attributes and performing the energy calculation for a building that represents the mean geometric values of the whole sample.

The average building would then represent the urban fabric that is being analyzed. This approach is similar to Quetelet's concept of "*average man*" in statistical science:

"*If the average man were determined for a nation he would present the type of that nation; if he could be determined from the ensemble of men, he would present the type of the entire human species*"[62]

To obtain the notional grid that represents a real urban fabric, the following parameters have to be measured. They will be

62 Hankins, 1908 p.64

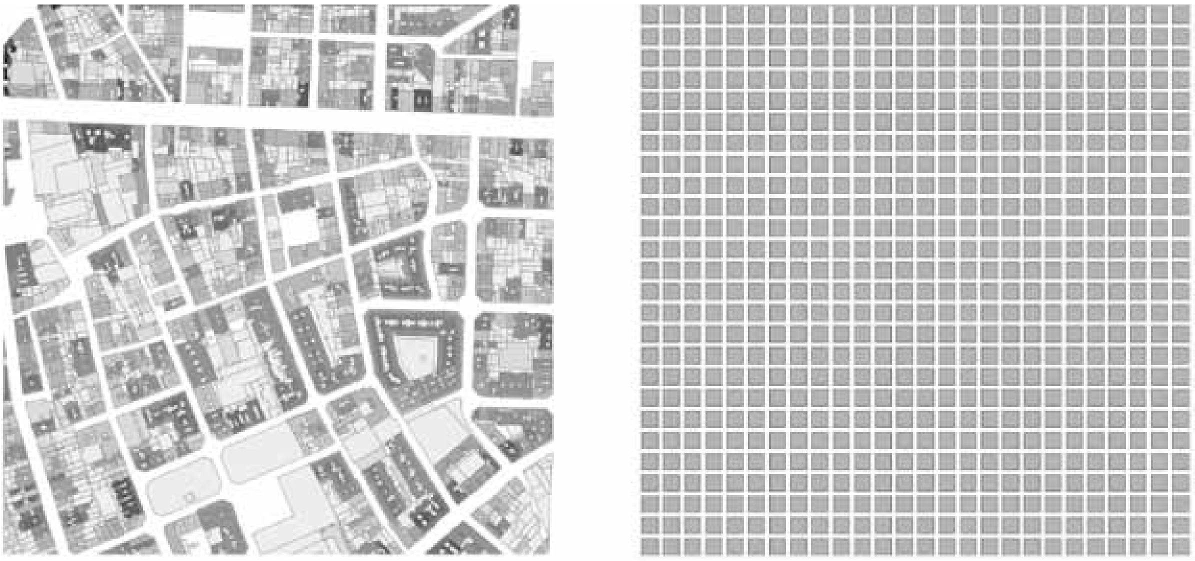


Fig.6-11 Urban sample (left) and its correspondent notional characteristic grid (right)

introduced as inputs in the transformation algorithms that have been purposely elaborated:

- Area of land covered in the sample (A)
- Side length of the sample (a)
- Ground Floor Area (GFA)
- Total building perimeter (P)
- Total floor area (TFA)
- Typical floor height (fh)
- Average building height (h)
- Perimeter in N-S axis (Pn-s)
- Perimeter in E-W axis (Pn-s)

The notional characteristic grid can be considered as a matrix (fig. 6-12) composed of a number "n" of building blocks with the following attributes:

- The area of the real urban sample and the notional characteristic grid are equal
- All blocks of the grid are equal
- Each block has the same GFA/P ratio than that calculated for the whole urban sample
- Each block has the same proportion of its perimeter facing the Northern-Southern quadrant and the Easter-Western quadrant than for the whole urban sample[63]
- The built up area and the total perimeter of the grid are the same as for the urban sample

The following inputs have to be obtained in order to create the grid that meets the previous requirements:

- An obstruction angle in the Northern-Southern axis for each block that is analogous to the mean obstruction angle in the same quadrants in the actual urban sample
- An obstruction angle in the Eastern-Western axis for each block that is analogous to the mean obstruction angle in the same quadrants in the actual urban sample
- A distance between blocks in the Northern-Southern axis that is analogous to the mean average distance in the same quadrants in the actual urban sample
- A distance between blocks in the Eastern-Western axis that is analogous to the mean average distance in the same quadrants in the actual urban sample
- A length of façades facing the Northern-Southern axis that is analogous to the length of façades facing the same quadrants in the actual urban sample
- A length of façades facing the Eastern-Western axis that is analogous to the length of façades facing the same

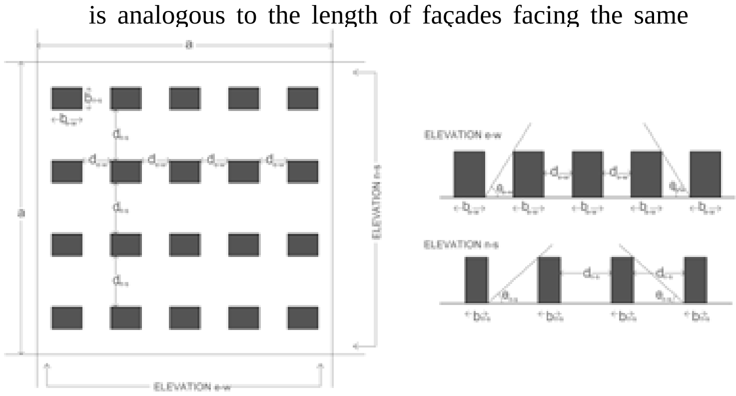


Fig.6-12 Notional characteristic grid. Main notations

63 Northern-Southern and Easter-Western are used as equivalents for main and secondary orientations in order to facilitate the visualization of the arguments. The deviation from North will eventually give the real directions

The following formulas have been inferred to allow the transposition from the real urban sample to the notional grid while retaining all the necessary attributes:

I) Direct Parameters

[F.1] Orientation:

$$\mathbf{Or = P_{n\text{-}s} / P_{e\text{-}w}}$$

[F.2] Block length in E-W axis:

$$\mathbf{b_{e\text{-}w}} = \frac{2*GFA*(1+Or)}{P*Or}$$

[F.3] Block length in N-S axis:

$$\mathbf{b_{n\text{-}s} = b_{e\text{-}w}*Or} = \frac{2*GFA*(1+Or)}{P}$$

[F.4] Total number of blocks in the grid:

$$\mathbf{n_t = P / (2*\, b_{e\text{-}w}*(1+Or))} = \frac{P^2*Or}{4*GFA*(1+Or)^2}$$

[F.5] Number of blocks per row, which has been determined to be equal to the number of blocks per row per simplification purposes:

$$\mathbf{n_{n\text{-}s} = n_{e\text{-}w} = n_{n\text{-}s}} = \sqrt{n_t} = \sqrt{\frac{P^2*Or}{4*GFA*(1+Or)^2}}$$

II) Derived Parameters

[F.6] Distance between blocks in the E-W axis

$$\mathbf{d_{e\text{-}w} = (a - n_{e\text{-}w}*b_{e\text{-}w})/n_{e\text{-}w}} = \frac{2*(1+Or)}{P} * a*\sqrt{\frac{GFA}{Or}} - \frac{GFA}{Or}$$

[F.7] Distance between blocks in the N-S axis

$$\mathbf{d_{n\text{-}s} = (a - n_{n\text{-}s}*b_{n\text{-}s})/n_{n\text{-}s}} = \frac{2*(1+Or)}{P} * a*\sqrt{\frac{GFA}{Or}} - GFA$$

F.8] Obstruction angle in the N-S axis

$$\mathbf{\theta_{n\text{-}s} = arctan\,(h/d_{n\text{-}s})}$$

[F.9] Obstruction angle in the E-W axis

$$\mathbf{\theta_{n\text{-}s} = arctan\,(h/d_{e\text{-}w})}$$

Where,

Or: Orientation ratio

$P_{n\text{-}s}$: Total perimeter in N-S axis (m)

$P_{e\text{-}w}$: Total perimeter in E-W axis (m)

$b_{e\text{-}w}$: Length of the block in E-W axis (m)

$b_{n\text{-}s}$: Length of the in N-S axis (m)

GFA: Ground Floor Area (m²)

P: Total perimeter (m)

n_t: Total number of blocks

$n_{e\text{-}w}$: Number of blocks per row

$n_{n\text{-}s}$: Number of blocks per column

$d_{e\text{-}w}$: Distance between blocks in E-W axis (m)

$d_{n\text{-}s}$: Distance between blocks in N-S axis (m)

$\theta_{n\text{-}s}$: Obstruction angle in N-S axis (degrees)

$\theta_{e\text{-}w}$: Obstruction angle in E-W axis (degrees)

h: Average building height (m)

The notional grid can be drawn up by finding the values of $b_{e\text{-}w}$, $b_{n\text{-}s}$, $d_{e\text{-}w}$, $d_{n\text{-}s}$ and h. The rest of the formulas are intermediate steps to find these critical parameters.

6.5.2 Concept demonstration

The hypothesis stated that the notional grid would retain relevant attributes in order to make meaningful energy predictions. The translation of absolute values, such as total built up area, from the irregular fabric to the regular grid can be intuitively understood. The computation of average values is less straightforward. The obstruction angle and distance between buildings are, for instance, much less intuitive and they require specific demonstration. In the following paragraphs, the steps to obtain such values are explained and demonstrated in a conceptual and graphic way.

For a better understanding, some common mathematical definitions that are used in the process are revisited:

Riemann's definition of the integral as the area under a curve:

"*Given a function of f on [a,b], its domain is partitioned into small subintervals. On each subinterval* $[x_{k-1},x_k]$ *we pick some point* $C_k \in [x_{k-1},x_k]$ *and use the y-value* $f(C_k)$ *as an approximation for f on* $[x_{k-1},x_k]$*. Graphically speaking, the result is a row of thin rectangles constructed to approximate the area between f and the x-axis. The area of each rectangle is* $f(C_k)\,(x_k - x_{k-1})$ *and so the total area of the rectangles is given by the Riemann Sum:* "

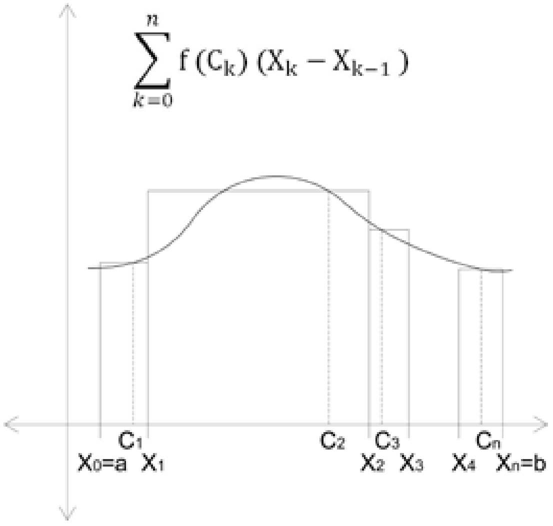
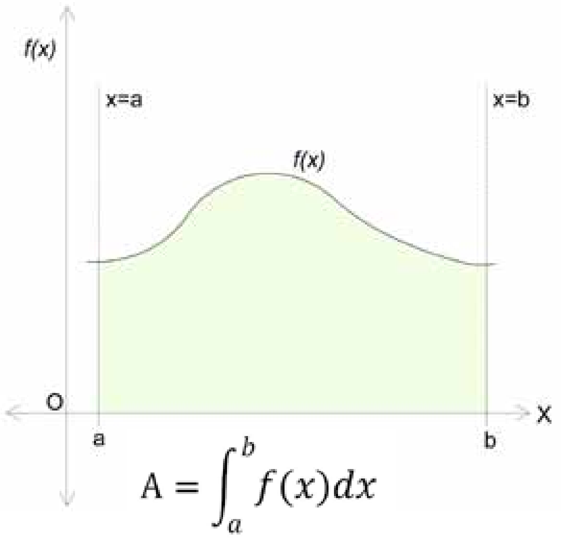


Fig.6-13 Riemann Summ

The accuracy of the Riemann-sum approximation improves as the rectangles get thinner. The limit would be reached when the width of the individual subintervals of the partitions tend to zero. This limit, if it exists, would be Riemann's definition of integral.

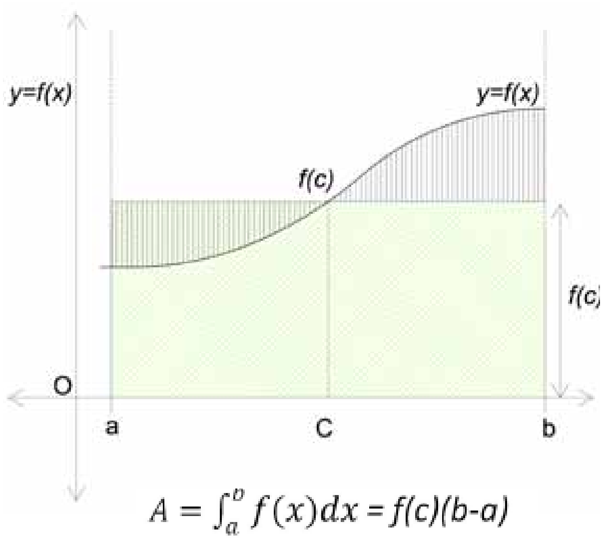
$$\int_a^f f(a,b)$$

According to Riemann's definition of integral, a function *f: (a,b)* with *f(x)*≥0 for the interval Xϵ[a,b,] can be integrated and then, the area limited by the graphic representation of f(x), OX axis and lines X=a and X=b is equal to: $\int_a^b f(x)dx$



Where A = Area of the colored zone, delimited by the function *f(x)*

According to the Mean Value Theorem, there is a value within the domain a,b C ϵ[a,b,] whose *f(c)* is equal to the height of a rectangle of base length (b-a) and whose area is equal to the area of the region defined by f(x).



f(c) is the mean value of the function *f(x)*in the interval [a,b] and it can be calculated as:

$$f(c) = \frac{1}{(b-a)} \int_a^b f(x)dx$$

Since $\int_a^b f(x)dx$= Area, then:

$$f(c) = \frac{1}{(b-a)} Area = \frac{A}{b-a} \qquad \textbf{eq. [1]}$$

Given a ground floor plan of an urban area (sample) defined by a squared polygon of dimensions a x a,(fig.6-14)

Let the sample be divided in *n* equal rectangles of dimensions a x b (fig.6-15).

It can be stated that the sum of the areas of all the rectangles (∑ Arect) is equal to the area of the polygon (Apol) that defines the sample.

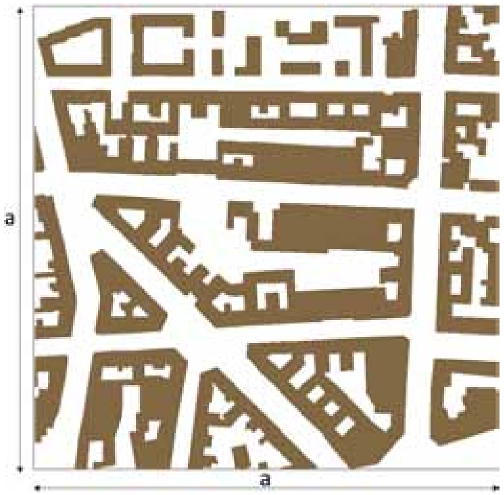


Fig.6-14 Urban sample

Fig.6-15 Urban sample divided in n equal rectangles

$A_{rect} = b*a$

$A_{pol} = a*a$

$\sum A_{rect} = A_{pol}$

then,

$n*b*a = a*a = a^2$

$b = a^2/\cancel{a}*n = a/n$

where

n=number of rectangles that divide the sample

b=width of the rectangular sections

a= side of the sample

Arect= area of the rectangular sections

Apol= area of the sample

Likewise, the sum of the built up area contained within the rectangles (fig. 6-16) would be equal to the total built up area in the sample and, conversely, the sum of the open space within all the rectangles would be equal to the total open space.

Fig.6-16 Area contained within the rectangle axb (in green)

$$GFA_{total} = \sum GFA_{rect}$$
$$OS_{total} = \sum OS_{rect} = a^2 - GFA_{total}$$

When the number of divisions is high, then the approximate built up area in each section could be calculated as:

$$GFA_n = (a/n) * \sum l_n$$

The Open Space area in each section would be:

$$Os_n = (a/n) * \sum d_n = (a^2/n) - GFA_n$$

Where $\sum l_n$ is the sum of the built segments that fall within the section and $\sum d_n$ is the sum of the open space segments that lay within the section (fig. 6-17)

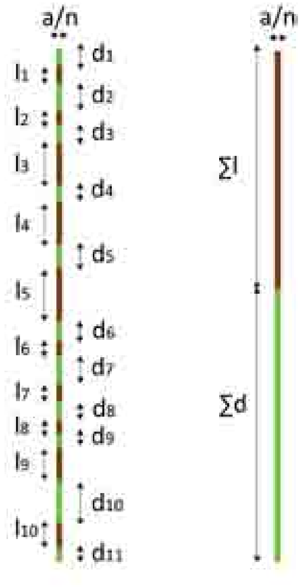


Fig.6-17 Rectangles are thinner when the number of divisions increases. The bar on the right is the equivalent when open space (d) and built up areas (l) are grouped

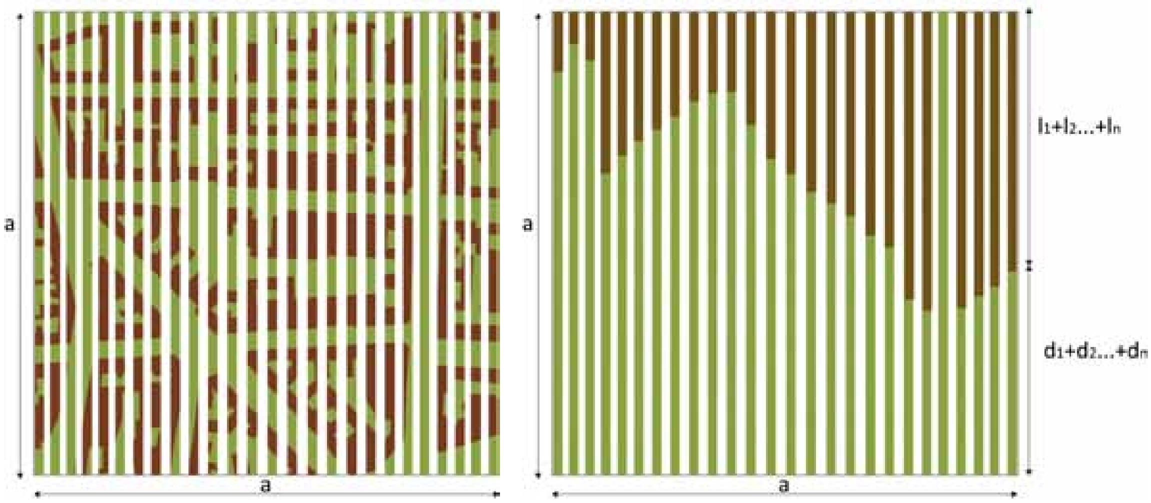


Fig.6-18 The similar graphic equivalent can be traced for the whole urban sample to illustrate the concept of average distance

According to Riemann's definition, the greater the number of divisions (n), the more accurate the computation of GFA and OS as sum of the segments within the section becomes. In an infinitesimal division, the rectangles could be considered as lines and the Open Space area as the distance between objects in that direction. As the order of the factors does not alter the result of the sum, the built elements (brown) and distance (green) can be grouped and arranged vertically (fig. 6-16). In this way, it is possible to measure the average length of open space in each direction. That gives an indication of the average distance between buildings in that same direction.

The boundary between the built area and open space in the second arrangement (fig.6-18 and 6-19) can be interpreted as a function *f(x)*, whose formula is unknown. Nevertheless, it is possible to calculate the mean value by using the formula

eq. 1 $$f(c) = \frac{A}{b-a}$$

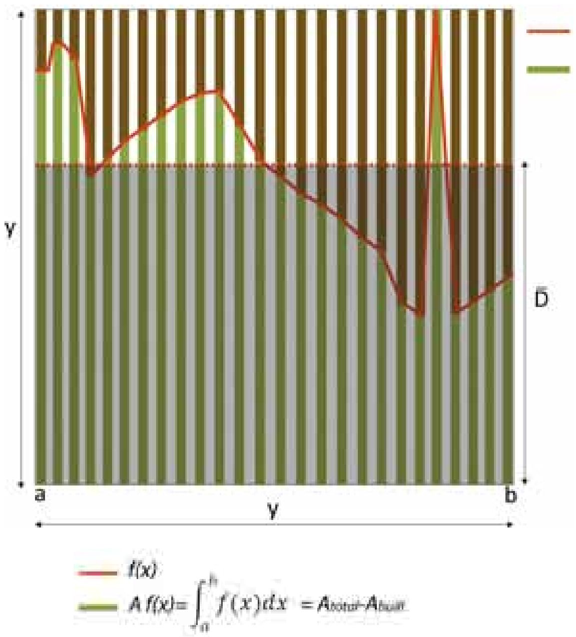


Fig.6-19 Calculation of average distance using Riemann's definition

$$f(c) = \frac{A}{b-a} = \frac{Atotal-Abuilt}{b-a}$$

since b-a=y and Atotal=y*y=y^2

then,

$$f(c)=\frac{y^2-Abuilt}{y}$$

$$D = \frac{y^2-GFA}{y}$$

Where,

D= Mean length of open space in the given direction

y= Side length of the sample

GFA= Total ground floor area

The same exercise can be repeated for the horizontal direction to obtain the mean distance between buildings on that orientation. The parameter D gives the average length of open space in the analyzed direction. If this value is divided by the number of elements "n" of each row and column, and indication of mean distance between built elements can be obtained.

$$D_{n-s} = \frac{(c_1 * y)*n + (b_{n-s} * d_1)*n}{(c_1 * b_{n-s})*n}$$

$$D_{e-w} = \frac{(d_1 * y)*n + (b_{e-w} * c_1)*n}{(d_1 * b_{e-w})*n}$$

6.5.3. Formulae development

The characteristic notional grid must retain the basic geometric properties of the actual fabric, which includes a sense of orientation. For this reason, its components will be defined with these considerations into account:

[a1] The depth to width ratio of the elements of the notional grid will be proportional to the ratio between the façades oriented towards the two prevailing directions in the sample ($b_{e-w}/b_{n-s} = P_{e-w}/P_{n-s}$)

[a2] The distance between elements is constant in the same axis but not in the orthogonal direction ($d_{n-s} \neq d_{n-s}$)

[a3] The distance from the blocks in the external files and rows to the perimeter is equal to half the distance between the blocks in internal files and rows

[a4] The matrix that contains the grid has the same number of columns as rows, therefore the number of files is equal to the number of rows and to the square root of the total number of elements (n=number of elements)

[a5] Even though there may be façades that are oriented towards different directions, other than the main one and its orthogonal, they have been grouped in such a way that only the four prevailing orientations are considered for the computations. It responds to simplification purposes and to the common use of the grid and the right angle in the construction of the city. However, a more detailed dispersal graph is given, as part of the study, for twenty eight real samples to support this assumption .

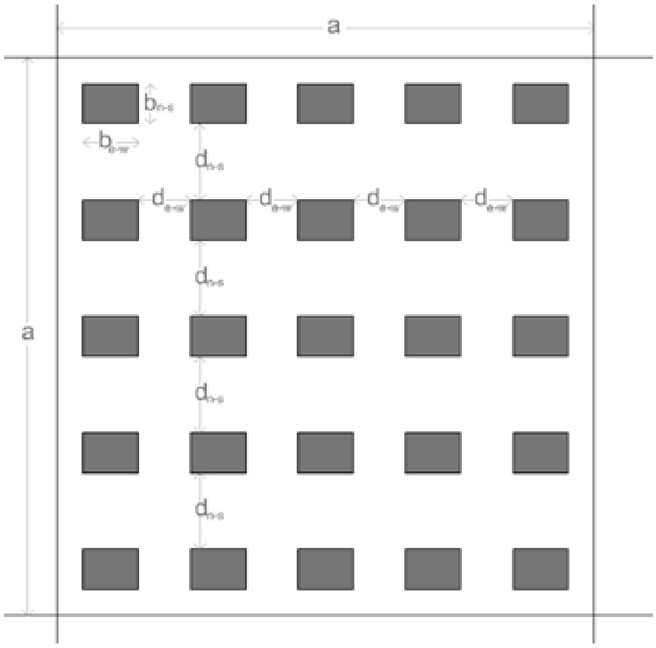


Fig.6-20 Sample and characteristic elements with orientation correlated to the actual fabric

[F.2] Formula to obtain the block length in E-W axis:

$$b_{e-w} = \frac{2*GFA*(1+Or)}{P*Or}$$

It is known that: $GFA = n_t * b_{n-s} * b_{e-w}$

And: $Or = P_{n-s}/P_{e-w} = b_{n-s}/b_{e-w} \rightarrow b_{n-s} = Or*b_{e-w}$ **[2.1]**

$P = 2\, n_t*(b_{n-s}+b_{e-w})$

$[b_{n-s}]$ is replaced by $[Or*b_{e-w}]$

$P = 2\, n_t*(Or*b_{e-w}+b_{e-w}) = 2*n_t*b_{e-w}*(Or+1)$

Which gives:

$n_t = P/[2*b_{e-w}*(Or+1)]$ **[2.2]**

In the initial formula [GFA = n_t*b_{n-s}*b_{e-w}] then [n_t] and [b_{n-s}] are replaced by their values in 2.1 and 2.2

$$\frac{P}{2*b_{e-w}*(1+Or)} * b_{e-w} * Or * b_{e-w} \quad Or * b_{e-w} = \frac{P*b_{e-w}*Or}{2*(1+Or)}$$

From this formula, b_{e-w} can be extracted as in the original expression:

$$b_{e-w} = \frac{2*GFA*(1+Or)}{P*Or}$$

[F.3] Formula to obtain the block length in N-S axis:

$$b_{n-s} = \frac{2*GFA*(1+Or)}{P}$$

The previous expression and [b_{n-s}=Or*b_{e-w}] are used to find b_{n-s}

$$b_{n-s} = \frac{2*GFA*(1+Or)}{P*\cancel{Or}} * \cancel{Or} = \frac{2*GFA*(1+Or)}{P}$$

[F.4] Total number of blocks in the grid:

$$n_t = \frac{P^2*Or}{4*GFA*(1+Or)^2}$$

In the formula [2.2], b_{e-w} is replaced by the expression [F.2] thus:

$$n_t = \frac{P}{2*\frac{2*GFA*(1+Or)}{P*Or}*(1+Or)} = \frac{P^2*Or}{4*GFA*(1+Or)^2}$$

[F.6] Distance between blocks in the E-W axis

$$d_{e-w} = \frac{2*(1+Or)}{P}\left(a*\sqrt{\frac{GFA}{Or}} - \frac{GFA}{Or}\right)$$

It is known that:

$d_{e-w}=(a/n_f)-b_{e-w}$

Where n_f= number of files = $\sqrt{n_t}$

n_t is replaced in the formula [F.4] and b_{e-w} is replaced in the formula [F.2], thus:

$$d_{e-w} = \frac{a}{\sqrt{\frac{P^2*Or}{4*GFA*(1+Or)}}} - \frac{GFA*2*(1+Or)}{P*Or}$$

This expression can be simplified as:

$$d_{e-w} = \frac{a}{\frac{P}{2*(1+Or)}\sqrt{\frac{Or}{GFA}}} - \frac{GFA*2*(1+Or)}{P*Or}$$

$$d_{e-w} = \frac{2*(1+Or)*a}{P*\sqrt{\frac{Or}{GFA}}} - \frac{GFA*2*(1+Or)}{P*Or}$$

$$d_{e-w} = \frac{2*(1+Or)*a*\sqrt{\frac{GFA}{Or}}}{P} - \frac{GFA*2*(1+Or)}{P*Or}$$

$$d_{e-w} = \frac{2*(1+Or)}{P} * \left(a*\sqrt{\frac{GFA}{Or}} - \frac{GFA}{Or}\right)$$

[F.7] Distance between blocks in the N-S axis

$$d_{n-s} = (a - n_{n-s}*b_{n-s})/n_{n-s} = \frac{2*(1+Or)}{P}\, a*\sqrt{\frac{GFA}{Or}} - GFA$$

Similar than in the previous case,

$d_{n-s}=(a/n_f)-b_{n-s}$

Where n_f= number of files = $\sqrt{n_t}$

n_t is replaced in the formula [F.4] and b_{n-s} is replaced in the formula [F.3], thus:

$$d_{n-s} = \frac{a}{\sqrt{\frac{P^2*Or}{4*GFA*(1+Or)}}} - \frac{GFA*2*(1+Or)}{P}$$

$$d_{n-s} = \frac{2*(1+Or)*a*\sqrt{\frac{GFA}{Or}}}{P} - \frac{GFA*2*(1+Or)}{P}$$

$$d_{n-s} = \frac{2*(1+Or)}{P} * \left(a*\sqrt{\frac{GFA}{Or}} - GFA\right)$$

6.5.4 Calculation Steps

The Urban Energy Index takes account of morphological parameters, such as urban intensity (GSI and FSI), compactness (Comp) and Orientation Ratio, together with location and climate, to estimate energy demand associated to urban form. Additionally, it can calculate the effect from variations in the typical floor height, glazing ratio, insulation, thermal capacity and albedo at urban scale. The calculation procedure takes these inputs to derive a notional grid following the procedure described in the previous section. Then it applies a 14-steps routine to obtain loads for heating, cooling and lighting. The whole process has been automatised using an spreadsheet, so that calculations are instantly performed. Optionally, the land use break down can be introduced. The model incorporates different specifications and default values for five building types (retail, industrial, facilities, office and residential) as it provides output results accordingly. Results are given as useful load per square meter of construction (built up area) for each building type. If different building types have been defined in the land use breakdown, aggregate values are given as average loads per unit of built up area and per square meter of land respectively. The former gives an idea about the average intensity of energy demand in relation with buildings and the latter is closer to the notion of energy density in the study area. The simplest way of using the model is, however, by assuming a single use, for instance a residential area, and to assess the energy performance of that urban form in relation with that specific function.

The calculation process consists on the following steps:

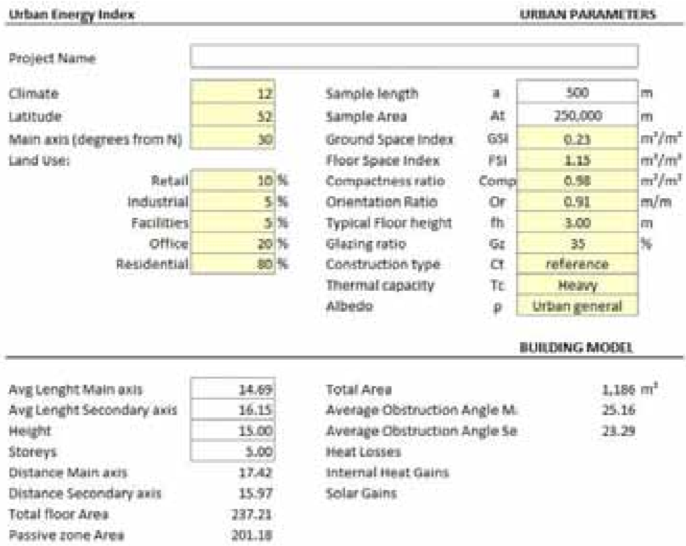


Fig.6-21 Interface of UEI spreadsheet. The cells that can be modified are colored in light brown, the others are intermediate outputs, some of which are only useful for calculation purposes

1- Heat Loss Coefficient. The heat loss coefficient takes into account the heat flow through all the elements that compose the building's envelope. Heat tends to flow from warmer spaces to cooler ones until both stabilize at the same temperature. As internal spaces are to be within comfort conditions, the heat flow tends to escape outdoors when the external temperature falls bellow comfort (or below the internal temperature if it has not been set to comfort). In this case, a heat loss occurs, whose intensity depends on the indoor-outdoor thermal difference, the conductivity of the building's envelope and the ventilation rate. For computation purposes, heat losses are grouped into two types: conduction and ventilation losses[64]. Conductive losses are proportional to the conductivity of each envelope's element by its area. For an urban sample, these elements may be diverse and heterogeneous but the model includes typical values for different specifications, from old buildings to low carbon developments. They can be checked or modified, either element by element or automatically, by selecting one of the construction types in a scroll-down menu. When a construction type is selected, U-values are automatically assigned for roofs, windows, walls and floors. The area of each element is then calculated and multiplied by its U-value. After that, ventilation losses are computed in relation to a predefined number of air changes per hour and the volume of the space[65]. Finally, all heat losses are aggregated and divided

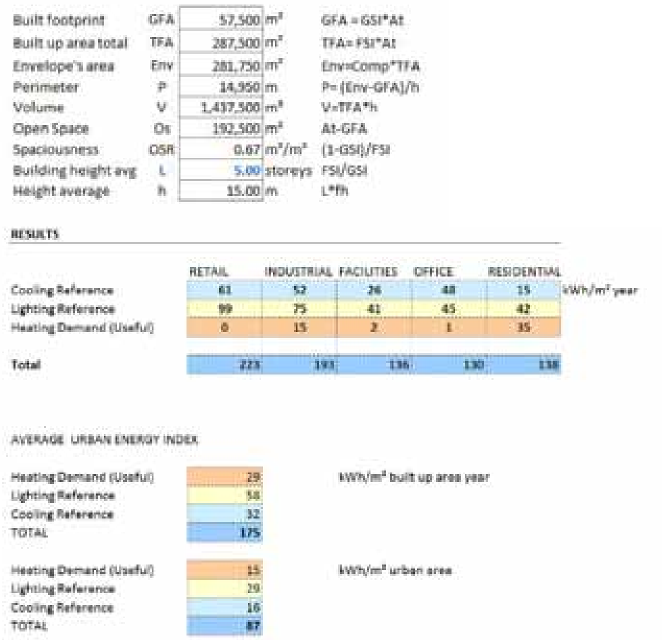


Fig.6-22 UEI results

64 Heat losses by radiation are not considered in the UEI

65 It has to be noted that ventilation rate should ideally depend on the number of occupants but this would introduce unnecessary complexity and uncertainty to the model

by the total floor area to obtain the Heat Loss Coefficient of the notional building in W/m²K.

2- Hourly Heat Loss. The hourly heat losses are calculated in relation with comfort and external temperature ((Ti-Te)*HLC). McCartney and Nicol's comfort algorithm for European countries[66] has been used to calculate the neutral temperature and the comfort range. The internal set-point temperature for heating and cooling is assumed as the lower limit of the comfort range in winter and as the upper limit in summer respectively. Hourly weather data is stored in the spreadsheet and it can be selected for each location. A design day that contains the mean hourly values has been specified for each month. The gross heat loss is calculated for each hour of the design day of each month. This is gives a first vision of the periods that are more likely to require additional heating or cooling

3- Internal Heat Gains. The internal heat gains are determined for each building type according to a predefined schedule. Typical values, from 5 to 25 W/m², are assigned, although they can be modified or replaced for more detailed parameters if they were known. Internal gains are defined for each month thus differentiations between weekdays and weekends are not possible at this stage.

4- Direct Solar Gains. The direct solar gains per floor area are calculated in several steps. First, the total vertical radiation in the direction of each façade is obtained. Then, knowing the sun position at each hour of the design day, the ratio of façade that is unobstructed is estimated. With this value and the glazing ratio, which is an input parameter, it is possible to make a close prediction of the solar radiation entering through the openings in each hour. The formula that has been used to perform the calculation is defined as:

$$\textbf{DSG} = \sum (\textbf{Gdv}_x * \textbf{Obs}_x * \textbf{A}_x * \textbf{Trans}) / \textbf{Total floor Area}$$

Where, DSG: Direct solar gains (W/m²)

Gdv_x: Vertical direct radiation of façade x

A_x: Glazed area on façade x (Total façade * Glazing ratio)

Obs_x: Ratio of façadex unobstructed

Trans: Window transmittance

5- Diffuse Solar Gains. Similarly, diffuse solar gains on four façades are calculated using the formula:

$$\textbf{Dfs} = (\sum (\textbf{Gdif} * (1+\cos(90+\theta))/2) * \textbf{A}_x * \textbf{Trans}) / \textbf{Total floor area}$$

Where, Dfs : Diffuse solar gains (W/m²)

$Gdif_x$: Diffuse horizontal irrandiance

A_x: Glazed area on façade x (Total façade * Glazing ratio)

Trans: Window transmittance

6- Reflected Solar Gains. In dense urban areas, reflected solar radiation can become almost as important as direct, especially in northern façades. The computation of reflected gains requires information on the reflectance of surrounding surfaces. By default, a reflectance value of 0.2 is assigned for

Total Solar Heat Gains

Total Solar Heat Gains (on four façades) = Dsg+Dfs+Rsg

Month	Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec	
N days per month	31	28	31	30	31	30	31	31	30	31	30	31	
Hour of day 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
6	0.00	0.00	0.00	0.43	12.00	10.04	14.28	0.00	0.00	0.00	0.00	0.00	
7	0.00	0.00	6.90	25.21	37.27	42.09	38.03	26.35	20.25	1.23	0.00	0.00	
8	0.88	11.42	36.35	60.88	65.51	66.17	66.10	62.15	48.85	25.21	3.35	1.11	
9	20.77	33.91	55.93	75.83	83.76	85.76	86.15	79.82	61.56	45.55	27.72	19.06	
10	38.10	54.49	68.83	79.37	78.54	72.96	72.62	83.34	74.09	61.06	45.14	34.08	
11	48.36	58.41	58.71	69.12	83.16	81.57	85.89	73.37	84.28	53.18	48.26	48.21	
12	29.76	37.14	45.00	53.23	48.48	44.84	49.07	58.54	48.12	36.59	32.13	27.50	
13	36.53	46.20	53.56	68.84	56.29	53.46	57.00	67.92	58.11	49.33	41.86	35.27	
14	37.01	49.65	56.87	82.45	58.43	54.66	59.73	72.48	59.89	47.45	38.67	33.07	
15	27.89	38.83	53.19	56.15	54.52	52.09	55.48	65.28	49.71	37.10	28.82	22.09	
16	6.82	27.36	37.96	39.96	36.70	34.96	38.35	43.57	36.93	23.88	5.94	4.95	
17	2.75	8.58	21.98	28.09	23.14	25.84	25.48	21.84	22.94	4.81	2.67	1.48	
18	0.00	0.96	3.29	5.00	13.34	18.09	15.22	6.66	3.88	0.33	0.00	0.00	
19	0.00	0.00	0.00	0.74	2.09	3.83	4.10	2.33	0.00	0.00	0.00	0.00	
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Day cumulative (wh/m²)	241	355.65	499.93	610.17	626.83	632.86	646.63	664.24	549.42	380.84	271.75	219.61	Year Total (kWh/m²)
Month cumulative (wh/m²)	7,460	9,958	15,498	18,305	19,432	18,986	20,045	20,592	16,482	11,806	8,153	6,808	173.52

Fig.6-23 Total solar gains table in UEI

66 McCartney & Nicol, 2002

all urban surfaces. It can be easily modified if the real values were known. The formula to calculate reflected solar gains is as follows:

$$Rsg= (\sum (Ggx*\rho*(-\cos (90+\theta)+\cos (90-\theta'))/2) * A_x*Trans) / \text{Total floor area}$$

Where, Rsg: Reflected solar gains (W/m²)

Ggx: Global Radiation incident on obstruction

A_x:Glazed area on façade x (Total façade * Glazing ratio)

Obs_x:Ratio of façade "x" unobstructed

Trans: Window transmittance

ρ: Reflectance

θ': arctan (hmedia/dist)

7- Total Solar Gains. The direct, diffuse and reflected gains are added together. Hourly values for monthly average days are provided in W/m²

8- Utilization factor. The utilization factor is the ratio between useful and total solar heat gains in a building. It can be calculated by using dynamic hourly models, although this procedure results inefficient for simple models. Alternatively, correlations have been derived from multiple runs in dynamic models that can be applied as shortcuts. The patterns identified in this way are generalized for their application in simpler steady-state tools. In this model, the utilization factor is a continuous function of time constant as proposed by Yohanis and Norton[67]:

$$\eta_G = 1-e^{\wedge}(-k/((Qg/Ql)-D))$$

Where, η_G= Utilization Factor

e: exp

Qg: Total gains (Internal + Solar)

Ql: Total losses

k,d: Utilization coefficients. They depend on thermal storage capacity (table 6-2)

Table.6-2 Utilization Factor (Van Dijk & Arkesteijn,1987)

Utilization factor	k=	d=
Light	1.14	-0.05
Heavy	1.55	-0.16
Very heavy	1.64	-0.16

9- Useful solar gains. Once the utilization factor has been calculated for each hour, it will be multiplied by the total solar gains to obtain the useful fraction, which is the proportion of solar gains that are used to remove auxiliary heating.

10- Continuous space heating or cooling. The calculation of heating starts from a conditional argument that is answered for every hour of the design days: if the internal temperature is within comfort range, the heating and cooling load for that hour is zero. If not, the useful gains are then subtracted to the losses to calculate the deficit or excess of heating that exists. As a result, every hour is assigned either a neutral value (zero)


Useful Solar Gains (w/m²)

Useful Solar Gains (w/m²) = Total solar gains x Utilization Factor

Month	Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec	
N days per month	31	28	31	30	31	30	31	31	30	31	30	31	
Hour of day 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
6	0.00	0.00	0.00	0.43	10.74	11.63	8.35	0.08	0.00	0.00	0.00	0.00	
7	0.00	0.00	6.79	16.37	17.75	14.56	10.15	7.98	7.19	1.11	0.00	0.00	
8	0.55	8.30	13.80	15.77	14.09	10.07	6.20	4.49	4.62	0.82	1.32	0.61	
9	8.17	12.75	16.81	15.00	13.38	8.32	4.13	2.21	3.15	0.00	6.04	7.00	
10	12.71	14.72	15.76	13.10	10.25	5.84	1.81	0.00	0.82	0.00	6.59	9.34	
11	12.00	12.72	13.67	10.26	7.52	2.75	0.00	0.00	0.00	0.00	5.44	8.96	
12	9.19	9.88	10.45	7.44	5.09	0.75	0.00	0.00	0.00	0.00	3.61	6.41	
13	8.97	8.86	8.91	6.51	3.77	0.00	0.00	0.00	0.00	0.00	3.23	6.41	
14	7.90	7.06	9.67	5.90	3.59	0.00	0.00	0.00	0.00	0.00	2.43	5.71	
15	6.56	6.80	9.81	6.14	4.10	0.00	0.00	0.00	0.00	0.00	2.18	4.69	
16	2.50	6.49	8.35	6.45	4.43	0.27	0.00	0.00	0.00	0.00	3.94	1.58	
17	1.23	2.22	7.63	5.43	4.84	1.85	0.00	0.00	0.00	0.00	0.50	0.58	
18	0.00	0.51	1.87	2.23	4.33	2.81	0.37	0.00	0.20	0.00	0.00	0.00	
19	0.00	0.00	0.00	0.74	2.83	3.49	2.08	0.81	0.00	0.00	0.00	0.00	
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Day cumulative (wh/m²)	71	88.92	123.92	111.93	106.69	61.95	33.49	16.32	15.98	1.93	32.29	51.37	Year Total (kWh/m²)
Month cumulative (wh/m²)	2,196	2,490	3,842	3,358	3,307	1,858	1,038	506	479	60	969	1,592	21.70

Fig.6-24 Useful solar gains table in UEI

67 Yohanis & Norton, 1999

that indicates that the building can perform within comfort under free running conditions, or a positive value if there is a requirement for additional heating or a negative value if there is overheating that needs to be removed with a cooling load. The yearly totals are also calculated in kWh/m²

11- Intermittent space heating or cooling. Similarly, heating and cooling loads are calculated but for occupied hours only. Those loads that occur beyond the hours of use are not computed.

These initial eleven steps are used for the estimation of yearly heating and cooling loads while the next three steps provide estimates for lighting loads. The increased insulation in new buildings has decreased the heating demand for new constructions across Europe. At the same time, the proportion of energy that is spent for lighting has increased. Even though the absolute figure may show little variations, the relative weight of lighting electricity has become an important share of the total bill.

12- Average Daylight Factor. It has been assumed that all working spaces are side-lit and the rough estimation method proposed by the BRE for early design is used[68]. The average daylight factor is defined for the whole building and it is calculated for the middle floor:

$$DF=M*W*\theta t / A(1-R^2)$$

Where,

M= Correction factor for dirt (0.7 by default)

W= Glazed area of windows (on average floor)

θ=Vertical angle in degrees

t= Transmittance of glass

A=Total area of floors, walls and windows (on average floor)

R=Averaged reflectance of ceiling, floor, walls and windows (0.5 by default)

13- Average hourly illuminance. The daylight factor indicates the proportion of external daylight that penetrates into internal spaces. It is an attribute of the building and as such, it is independent from weather conditions. However, to know whether internal light is enough to satisfy the users' needs, it is necessary to obtain information about outdoors daylight availability. External illuminace can be measured outdoors, on an unobstructed plane, or it can be derived from solar radiation by using luminous efficacy factors[69]. Since the irradiance on the horizontal plane is included in the model, as part of the heating and cooling calculations, this method is preferred. Correlation factors between illuminance and irradiation are however site and seasonal specific. Numerous empirical studies have come up with factors for locations such as Osaka, Geneva or Calabria[70]. Other studies have proposed correlations in relation with Solar Altitude[71]. All these possibilities have been analyzed and, due to the simplicity of average models, the average daylight available is obtained as a result of the following factors of luminous efficacy[72]:

-Direct = 104 lm/w

- Global = 110 lm/w

- Diffuse = 120 lm/w

The diffuse efficacy (120 lm/w) is used for DF calculations, because the method to calculate DF has primarily considered overcast sky as typical sky condition. This factor is multiplied to the hourly diffuse horizontal radiation to obtain outdoors daylight conditions. The DF is applied to this value and the result is an estimate for the internal illuminance.

14- Electric lighting. To establish the proportion of light that is provided artificially, internal spaces are divided into passive and non passive zones. Those parts of the notional buildings that are beyond a distance that is twice the floor to ceiling height are automatically considered as non passive, and they will be artificially lit at all occupied times. The passive zones are assigned a datum, which is the minimum light levels that are required, as average, for that building type. If the illuminance, which was calculated in the previous step, is below the datum, artificial lights are required for the passive zone as well (the non passive zone is constantly lit by artificial means on occupied hours). The same procedure is repeated for every occupied hour. The lighting power that is installed has been also assigned by default, thus for residential buildings 10 w/m² are prescribed, which would give a maximum around 65kWh/m² per year without daylight contribution. The electric load is reduced as daylight penetrates into the building and displaces electric bulbs.

These fourteen steps have been applied to the notional grid that was created and explained in the previous chapter. Results provide an idea about the effect of density, obstructions and other typical features on the urban sample, but they cannot be interpreted as absolute values. One of the advantages of this model is lies on the flexibility of its attributes to be easily customized so as to test the influence of specific parameters or to introduce more precise definitions of the urban fabric. Subsequent development of the tool has addressed the integration of the model in GIS to obtain automatic assessment of the urban form.

68 BRE 1996

69 Muneer, 2004

70 De Rosa et al, 2008

71 Hopkinson et al, 1966

72 Szokolay, 2004

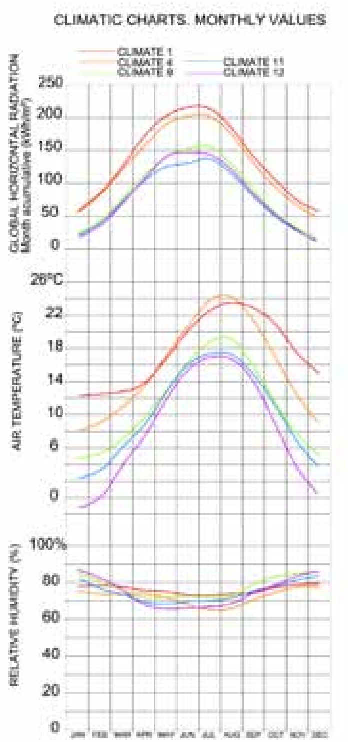
6.6. Model validation

The validation of the model has consisted on two different stages. First, the validity of the notional grid as to represent the relevant attributes of the study area. A set of twenty eight urban samples was selected and simulated under two different methods: using a detailed model (all buildings being drawn up in detail) and using the simplified model proposed in this thesis (notional grid). Both simulations, detailed and simplified, were performed in Climatelite[73], an environmental modeling software tool that incorporates algorithms from LT. A close correspondence was found between the two modeling techniques, which supports the hypothesis that a simplified model can be used to perform rapid assessments in large urban areas. In the second validation stage, the Urban Energy Index (UEI) spreadsheet model was tested against simulations performed in Climatelite. The results from the spreadsheet were compared against the results obtained with Climatelite, using both detailed and simplified models. In general terms, the UEI spreadsheet compared well to the reference tool. Correlations ranged from $r^2=0.75$ to $r^2=0.82$ for comparisons against detailed and simplified Climatelite models respectively.

For the whole calibration and validation process a set of twenty eight representative urban samples was compiled. They represent a range of different climates and morphological variations to be found in cities across Europe. In the initial selection, five cities were picked up from different latitudes and continental positions:

- Berlin (52º N, 88,966 degrees hour)
- London (51º N, 75,632 degrees hour)
- Paris (48º N, 65,715 degrees hour)
- Barcelona (41º N, 24,291 degrees hour)
- Madrid (40ºN, 38,475 degrees hour)

These five climates can be classified as temperate, with seasonal variations that makes them fluctuate between underheating and overheating conditions (fig. 6-25). All these cities are meant to require a heating load and, in some cases, a cooling load as well. The Spanish cities present the mildest winter and the warmest summer, while solar radiation is significantly higher there than for the other locations. Berlin is the only sample where average monthly temperature falls below zero in winter and where, together with London, summer average temperature remains below comfort levels. Weather data has been extracted from Climatelite database, in order to keep consistency during the validation process (results would be affected had a different weather database been used). It contains hourly values for air temperature, relative humidity, diffuse and beam solar radiation and wind speed. There is no reference about the origin of weather data and the European climatic classification that it has been based



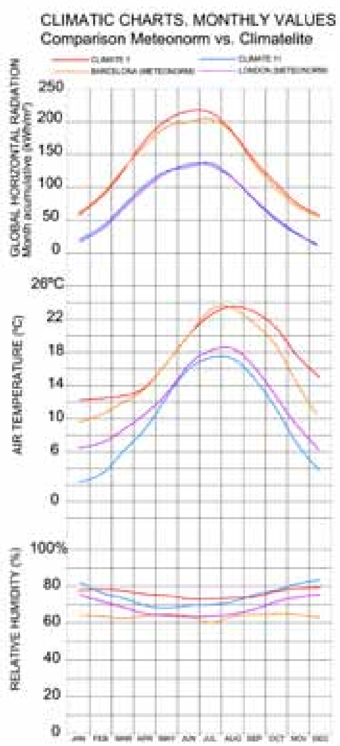


Fig.6-25 Climatic data of the five selected cities (left) and comparison of weather databases (right)

73 www.bre.co.uk/page.jsp?id=996 [last visited 28.01.2013]

on (fig. 6-26) in any of the Climatelite supporting documents. A comparison was drawn between its databases and a known source (Meteonorm) in order to check the reliability of the data. More specifically, Barcelona and London weather data from Meteonorm were compared against their correspondent climates in Climatelite (climates 4 and 11 respectively). Although slight variations in air temperature and relative humidity were unveiled, they were not so significant as to discard the Climatelite data. Meteonorm datasets are site specific and therefore their main value is the accuracy of its data whereas Climalite classification has prioritized generalization over precision.

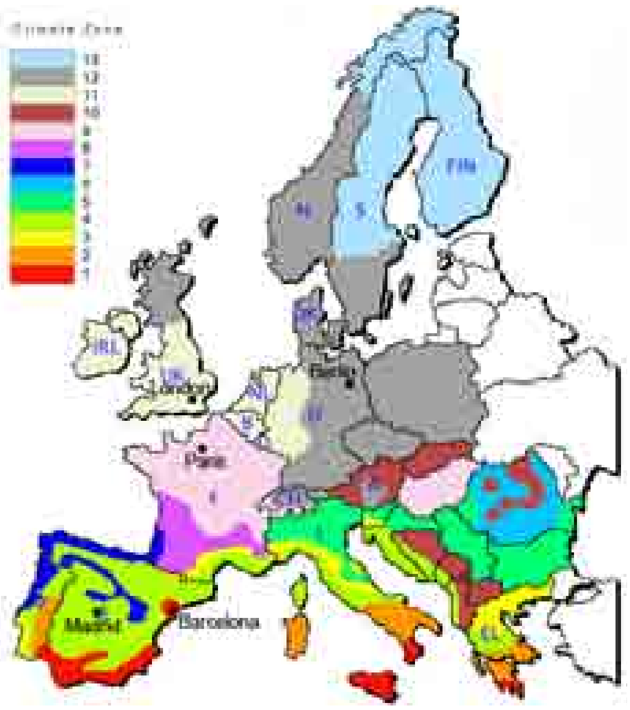


Fig.6-26 Map of Europe showing the five selected cities and climate zones (after Climatelite)

In order to compile a broad range of urban forms, five to six samples were selected in each city, for a total of 28 samples. This second selection aimed to compile different urban typologies, which were characterized by key performance parameters: floor space index, coverage, and compactness. Priority was given to areas with a moderate to high density, since it was assumed that the Urban Energy Index would be less accurate in low density areas. However, several suburban examples were included so as to confirm the performance of the tool in those cases. For each city, the selected urban typologies aimed to include, at least:

- One dense central district with a certain regularity in the streets layout
- One dense but irregular sample
- One area of linear open blocks
- One mixed zone with open blocks
- One sample with terraced and detached buildings

Variations within these typologies can be found across cities but they keep a consistency to allow meaningful comparisons.

The twenty eight samples are illustrated at the following pages. They were delimited by 500x500 m rectangles and they were also redrawn in order to establish a first visual description of the urban typologies. Different scales of grey were used to depict building height to create 2.5D maps. It allows a clearer visualization and the intuitive identification of samples as recognizable urban patterns. The distinction between open space and built areas stands out in this collection. A great portion of the central city is characterized by the presence of large compact blocks of moderate height (five to seven floors) while the open realm is scarce. The proportion of white (open space) increases as we move towards urban arrangements which are based on linear blocks and stand alone buildings. In low density samples, buildings seem to float in the openness, while the distinction between public domain and private open space has been blurred. In many of the samples, an underlying orthogonal layout can be traced. Sometimes it is so clear that it becomes a characteristic feature of the urban fabric, as for example in Barcelona's Eixample, Madrid's Goya or Berlin's Herrfurthplatz. In other cases, a great diversity of façade orientations coexist but still, two prevailing axis can be discovered. This is the case in Paris' arrondissements, London's Regents Park or Putney.

6.6.1. Urban Morphometric Parameters

Classic studies of urban morphology were primarily concerned with typology and archetypes to the restore stylistic coherence in subsequent urban interventions. The present study does not deny the relevance of the educated urban analysis as it aims to provide additional supporting tools to increase the information on urban attributes. Neither does it neglect the welfare of people living in the city, as that is the ultimate target of the whole research. However, knowledge on the effect of urban form does not restrict other possible approaches to urban analysis. It rather identifies potential weaknesses and the effect of alternative solutions. The visual experience of the urban form provides an intuitive diagnose based on logical deduction and observation. For instance, a dense fabric is perceived as dark and enclosed because it presents high levels of obstruction, which prevent solar access to the buildings. For the same reason it may be also associated with high heating demand. On the other hand, buildings in these areas are often very compact and therefore heat losses through the envelope are moderate. The quality of construction can be also connected to urban form as long as this can be associated with a specific period. The central

Fig.6-27 Graphic computations with urban samples to calculate envelope's area. Left:: Polygons with information of building height. Center: DEM Right: Real area, façades appear as lines because the area represented by each cell is higher

districts were typically built before the nineteen thirties, a time when insulation was inexistent. However, post-war reconstruction and renovation plans may have altered the composition of building's envelope in many of those areas. The uncertainty of inferences derived from observations increases when all the factors involved are considered. The elaboration of objective deductions based on calculations is an alternative to reduce the uncertainty.

The use of the Urban Energy Index tool requires the use of morphometric parameters in the study areas. The procedure to obtain such values is based on GIS and its spatial analytic capabilities. GvSIG was used to measure the relevant variables in the twenty eight urban samples of the validation process. In some cases, data collection was straightforward, whereas a sequence of several steps was required to obtain other parameters, such as orientation and envelope`s area. Cartographic information had been previously collected and processed to incorporate building height, which was missing in some samples. The main spatial variables were obtained in GvSIG as follows:

- **Ground Floor Area (GFA).** The 'area' tool was applied to a selection of features that filtered all polygons whose field "height" being greater than zero.
- **Total Floor Area (TFA).** The sum of the area of all building polygons multiplied by the number of floors of each of them was calculated to obtain the TFA of the sample.
- **Envelope's Area.** The calculation of exposed envelope is relevant for the definition of compactness and it requires several steps. First, polygons with the same height are dissolved in order to merge buildings that are adjacent and share the same height. Then, vectors are rasterized to create a Digital Elevation Model (DEM) from the shapefile by using the "rasterize" tool from "Sextante" plug-in. The height of the buildings is defined as the Band-value of the new raster. The raster has assigned a value "-99.999" to all pixels without a height (open spaces). We need to transform those values in zero, in order to ensure a correct computation. A conditional order is applied using the map calculator tool: "if (layer band <0,0, layer band). Now, a value "zero" is assigned for the pixels that represent open space and a height dimension is assigned to all pixels that form part of a building. Sextante algorithm "real area" calculates the real area of each cell in the raster, taking into account the size of the cell and its slope. A new raster is created with this information (fig. 6-27 right). Cells that depict horizontal surfaces (roofs and ground) contain a value that is equal to the area of the cell, whereas in vertical elements (façades) the value of the cell accounts for the vertical development of that element (i.e. the area of façade). Applying the "Basic Statistics" tool to the new raster, the total sum of the areas in all cells can be obtained. To this value, the Open Space Area is subtracted (as it is not part of the buildings' envelope) and the result is the area of the envelope for all buildings within the sample.
- **Volume.** The total volume of all buildings included in the sample is calculated by applying "volume calculation" Sextante algorithm to the DEM created in the previous step.
- **Orientation Ratio.** The tool "Orientation" from Sextante is applied to the DEM in order to assign a deviation from North to each pixel. Then, the GvSIG built-in tool "Color tables" is applied to the new raster to create band steps every 30º. An histogram is created and, by selecting "remove extremes" and color mode "RGB", it can be saved as an spreadsheet. In an spreadsheet editor (Excel or OpenOffice) the tabulated orientation values

28 URBAN SAMPLES

BARCELONA
C1, 40º N

Eixample

Sants-Badal

El Besós i el Maresme

MADRID
C4, 41º N

Goya

Embajadores

Pinar del Rey

PARIS
C9, 48º N

11th Arrondissement

3rd Arrondissement

13th Arrondissement

LONDON
C11, 51º N

Marylebone

Mayfair

Regent's Park

BERLIN
C12, 52º N

Herrfurthplatz

Charlottenburg

Schillingstrasse


La Font d’en Fargues


Pedralbes


Les Planes


Simancas


Piovera


Valdemarín


La Villette


Amérique


Putney


Kilburn

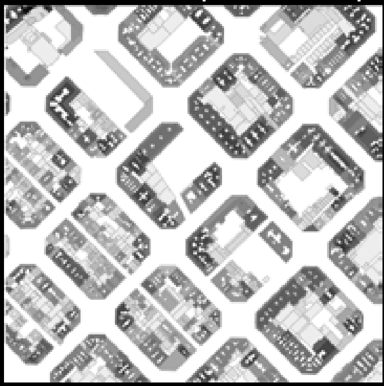

Wembley


Gielower


Westend

28 URBAN SAMPLES. Morphometric parameters

BARCELONA
C1, 40º N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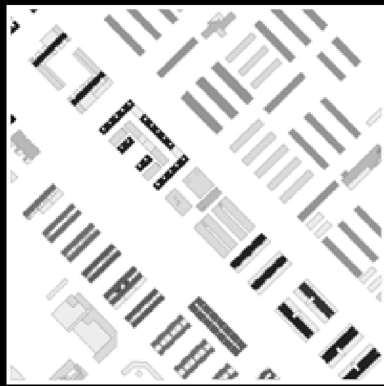
FSI: 2.28 GSI: 0.58 Comp:1.07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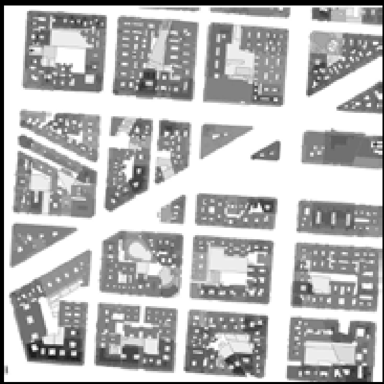
MADRID
C4, 41º N


FSI: 3.41 GSI: 0.53 Comp:0.79


FSI: 3.25 GSI: 0.70 Comp:0.83


FSI: 1.01 GSI: 0.21 Comp:1.08

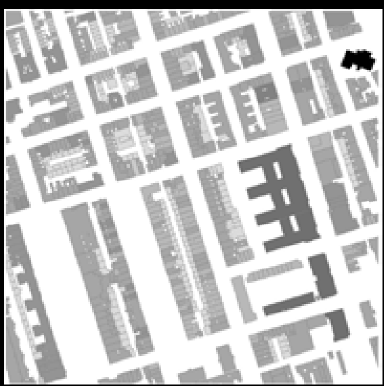
PARIS
C9, 48º N


FSI: 1.90 GSI: 0.37 Comp:0.93

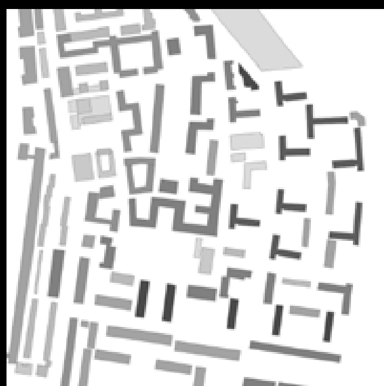

FSI: 2.05 GSI: 0.51 Comp:1.01


FSI: 0.90 GSI: 0.27 Comp:0.87

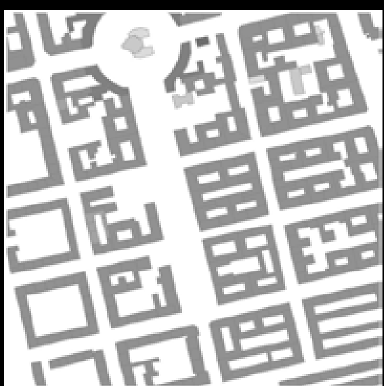
LONDON
C11, 51º N


FSI: 2.31GSI: 0.46 Comp:0.73


FSI: 2.86 GSI: 0.60 Comp:0.56


FSI: 1.15 GSI: 0.26 Comp:0.96

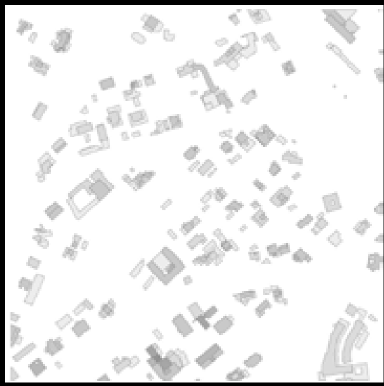
BERLIN
C12, 52º N

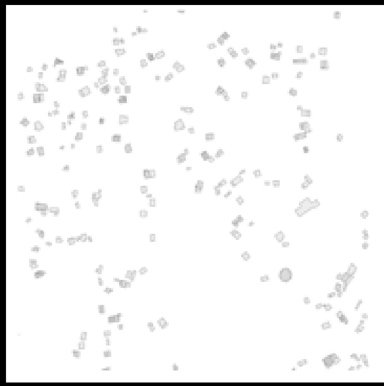

FSI: 2.05 GSI: 0.41 Comp:0.69


FSI: 2.35 GSI: 0.45 Comp:0.57


FSI: 1.07 GSI: 0.15 Comp:0.69


FSI: 0.94 GSI: 0.30 Comp:1.37

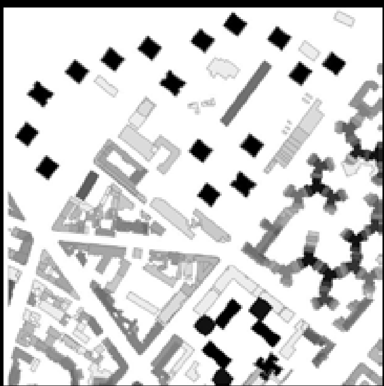

FSI: 0.29 GSI: 0.15 Comp:1.33


FSI: 0.06 GSI: 0.04 Comp:2.24


FSI: 1.23 GSI: 0.29 Comp:1.15


FSI: 0.31 GSI: 0.19 Comp:1.47


FSI: 0.11 GSI: 0.07 Comp:1.35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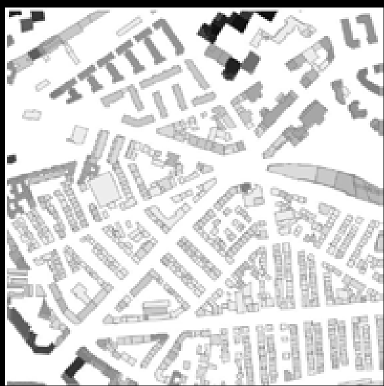
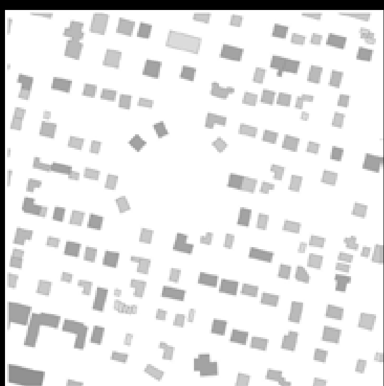

FSI: 0.99 GSI: 0.32 Comp:1.11


FSI: 0.59 GSI: 0.17 Comp:1.00


FSI: 0.83 GSI: 0.34 Comp:0.96


FSI: 0.81 GSI: 0.29 Comp:0.96


FSI: 0.55 GSI: 0.17 Comp:1.00


FSI: 0.48 GSI: 0.16 Comp:1.04

Number of floors

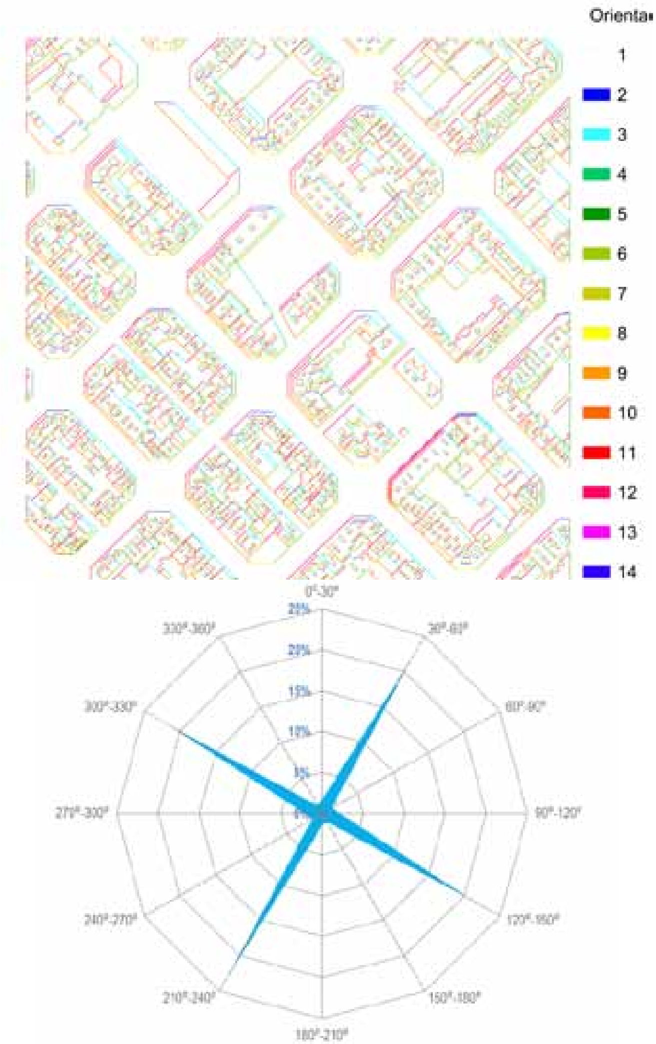


Fig.6-28 Orientation map obtained in GvSIG and distribution radar chart showing the two prevailing orientations (30º-60º NE-SW and 120º-150º SE-NW)

(0º, 30º, 60º, 90º, 120º, 150º, 180º,210º,240º,270º, 300º, 330º and 360º) are computed to obtain the length in each interval direction. The Orientation ratio is then obtained by dividing the perimeter's length in the main direction by the perimeter's length in the secondary direction.

- **Perimeter length.** It would be possible to measure perimeters in GvSIG, but it is more accurate and direct to apply the following formula:

$$P_{av}=(Env-GFA)/h_{av}$$

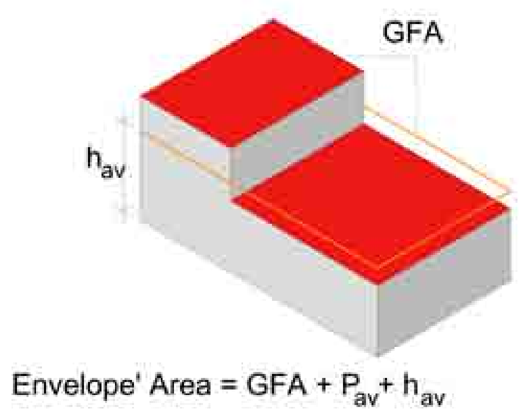
Where,

P_{av}: Average perimeter (m)

Env: Envelope's area (m²)

GFA: Ground Floor Area (m²)

h_{av}: Average building height (m) Obtained as (FSI/GSI)*typical floor height



All relevant data was compiled and systematically stored in twenty eight information sheets, one for each urban sample. The complete collection of data sheets can be consulted in the appendix

6.6.2. Simulations

Once the main parameters of the twenty eight samples were measured, it was possible to calculate the notional characteristic grids for each of them. For each sample, the transformation algorithms described above were applied in order to obtain the mean values that will be used to estimate energy loads in the simplified model. The initial hypothesis stated that the average energy demand of the notional grid would be equivalent to the average energy demand of the urban sample that it represents. In order to test this hypothesis, all selected samples were modeled twice in the energy software tool Climatelite:

- In the first simulation, the urban fabric was defined with great detail. Every building was drawn from its footprint and extruded to its real height.
- In the second model, the actual geometry was replaced by the notional grid. Buildings were introduced as regular blocks defined by the average length, depth, height, orientation, compactness and separation obtained from the formulas.

Those parameters that were not considered as definers of urban morphology were kept constant in both models. Window to wall ratio was assumed as 35% in every façade and reference U-values were assigned to walls, roof and windows. Five building types were included in each simulation model: retail, industrial, facilities, office and residential (fig. 6-30). They were randomly distributed around the model, in order to cover a broad range of orientations and floor levels. These building types are merely indicative of how different internal conditions respond to the same urban form. It is not claimed that they represent all the possible variants that exist in real cities (fig. 6-31).

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side	a	500	m	500m
Built footprint	GFA	129,505	m²	GIS
Built up area total	TFA	707,985	m²	GIS
Envelope's area	Env	704,534	m²	GIS
Volume	V	2,122,751	m³	GIS
Orientation Ratio	Or	1.00	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	120,495	m²	At-GFA
Perimeter	P	35,062	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	17,558	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	17,504	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.00	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.52	m²/m²	GFA/At
Floor Space Index	FSI	2.83	m²/m²	TFA/At
Building height avg	L	5.47	storeys	FSI/GSI
Height average	h	16.40	m	L*fh
Spaciousness	OSR	0.17	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	14.80	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	14.75	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	593.27		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	24.36		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	5.73	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	5.78	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	70.74	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	70.60	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	2.86	m/m	h/dm
Average urban canyon main	Ucs	2.84	m/m	h/ds
Passive Zone	PZ	124,938	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.96	m²/m²	PZ/GFA
Model floor height	fh'	3.28	m	fh'= h/integer (L)

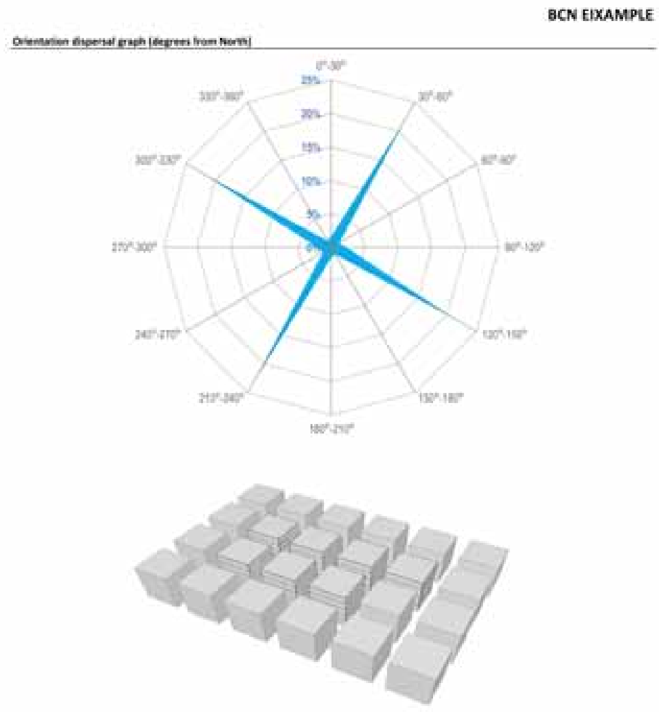


Fig.6-29 Data sheet for Barcelona's Eixample urban sample (to the right bottom is the equivalent notional grid)

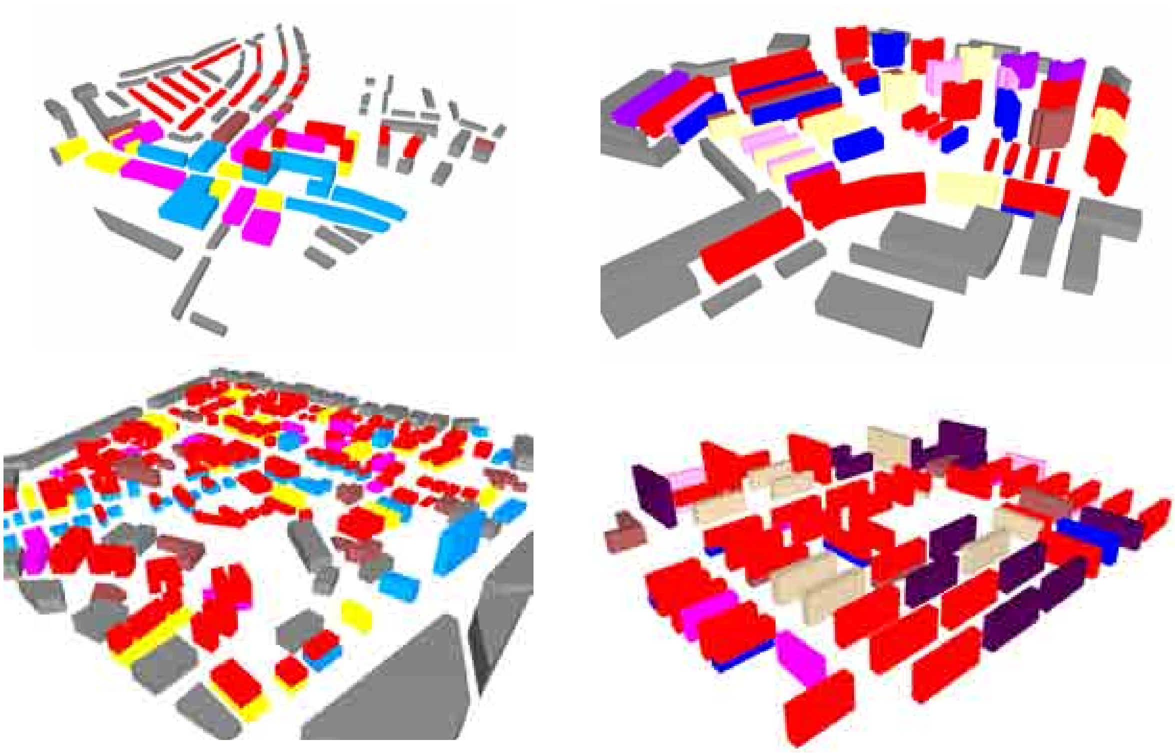
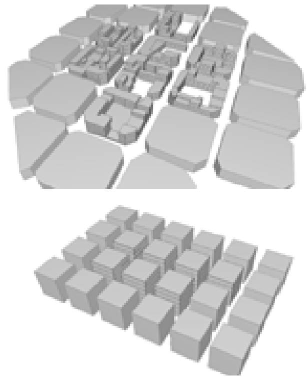


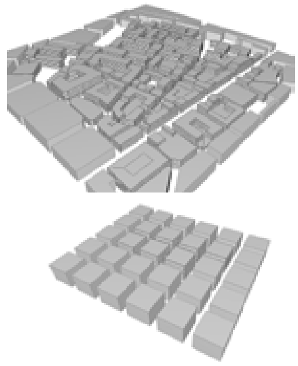
Fig.6-30 Climalite models of (from top left, clockwise): Wembley (LON), Simancas (MAD), Besós, (BCN) and la Pinar del Río (MAD), and. Each color represents a different building type

28 URBAN SAMPLES. Notional Grids

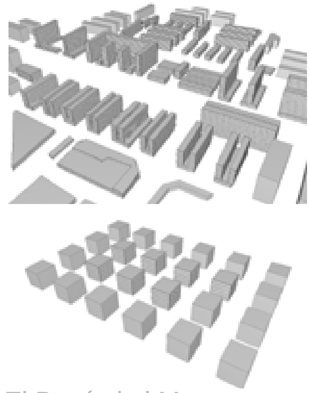
BARCELONA
C1, 40º N



Eixample

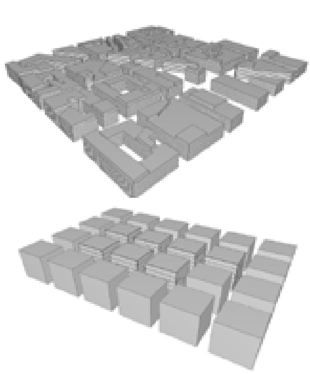


Sants-Badal

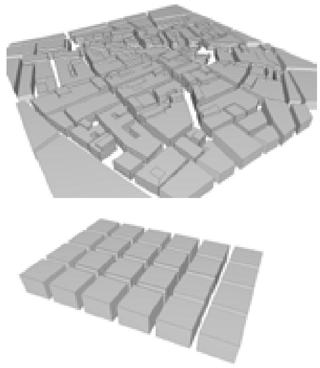


El Besós i el Maresme

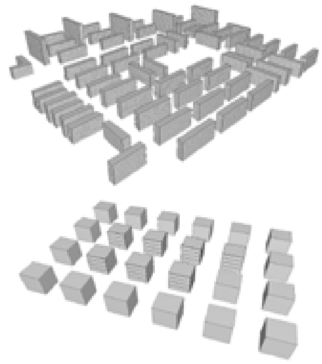
MADRID
C4, 41º N



Goya

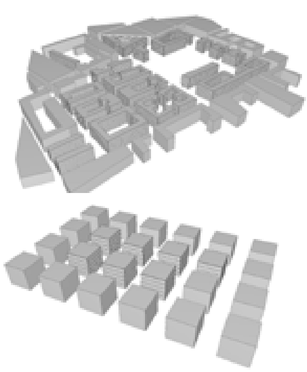


Embajadores

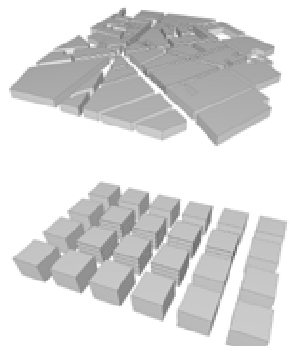


Pinar del Rey

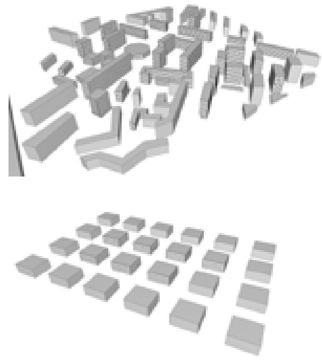
PARIS
C9, 48º N



11th Arrondissement



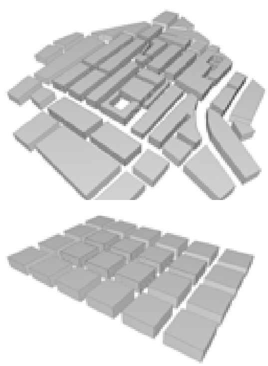
3rd Arrondissement



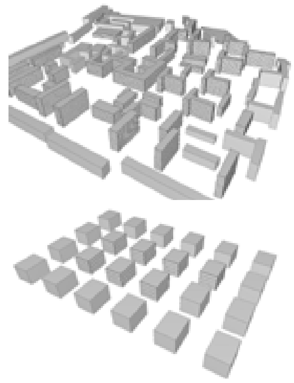
13th Arrondissement

LONDON
C11, 51º N

Marylebone

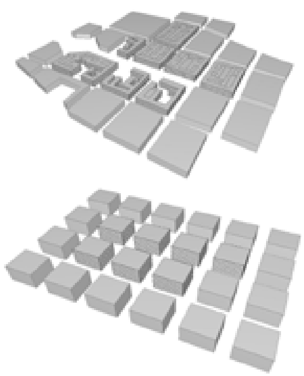


Mayfair

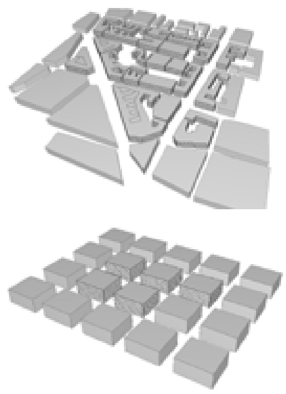


Regent's Park

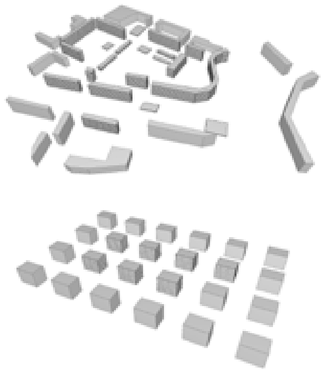
BERLIN
C12, 52º N



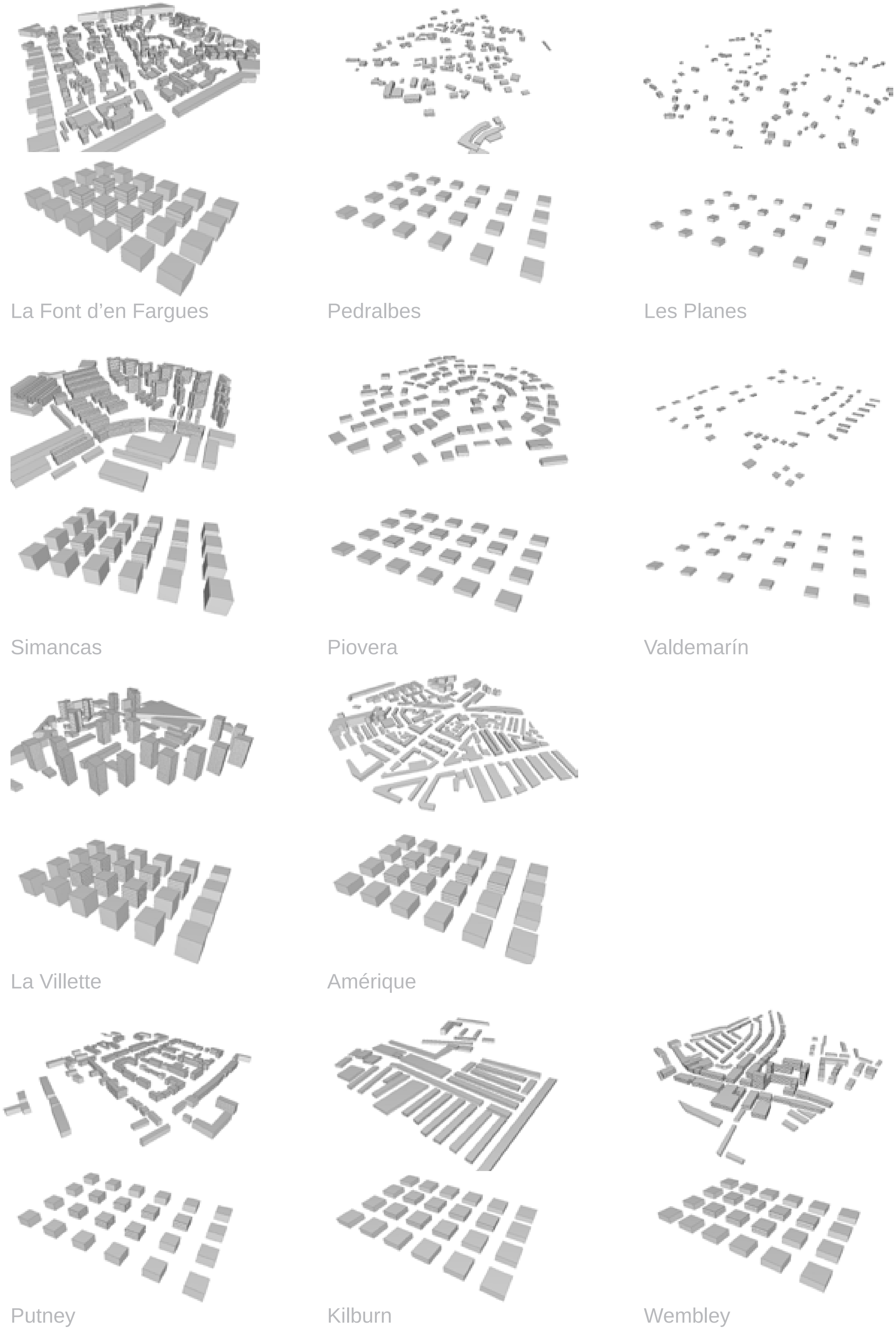
Herrfurthplatz



Charlottenburg



Schillingstrasse



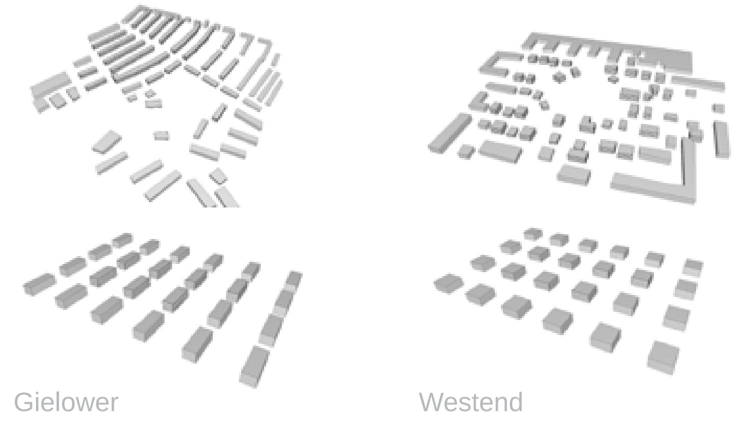


Fig.6-31 Detailed models(top) and notional grids(bottom) as simulated in Climatelite for validation purposes

6.6.3. Validation I: Notional Grid (simplified model) vs. Detailed Model

As it was mentioned in the previous paragraph, every sample was modeled twice: the first time, the reality was represented as truthful as possible, and a second time a simplified model, using the notional grid, was used instead. Since every sample belongs to a specific city (Madrid, Barcelona, Paris, London and Berlin), the energy loads were initially calculated for the climatic conditions of those locations. However, in order to gather further elements for the validations, all samples were also simulated under the five climates. The settings of the models were devised in such a way that each simulation provided a total of 20 outputs, including average cooling, electricity, heating and hot water loads for each of the five building types (retail, industrial, facilities, office and residential). A total of 280 simulations were undertaken (28 samples X 5 climates x 2 model types) and, since each model provided 20 outputs, 5,600 values were obtained for the validation.

The correlation coefficient was calculated to evaluate how detailed and simplified models matched. The overall scatter plot (fig. 5-32) and r^2 showed a high correlation between both models (r^2=0.91), which confirms the strength of the notional grid as to provide meaningful energy estimates. If correlations are analyzed by building types, the strongest correspondence is found for industrial buildings (r^2=0.93), followed by residential (r^2=0.84), whereas office and retail have a similar deviation (r^2=0.81 and r^2=0.80 respectively) and facilities present the lowest correlation (r^2=0.76). Since building types have been arranged randomly, their outputs can differ due to their relative position in the models. The important finding is however the high overall correlation, as it represents the average values for the whole sample.

The correlation analysis by loads shows a strong correspondence for heating and cooling (r^2=0.94 and r^2=0.92 respectively) whereas "electricity and appliances" presents a weaker performance. Electricity loads seem to be clustered by building type and the simplified model seems less sensitive to variations in input parameters than the detailed model. This can be partly explained by the fact that the load is a combination of fixed values (appliances and equipment) and lighting, which is the only portion of the load that can actually respond to variations in urban morphology. Looking into heating load's correlation more closely, the simplified model seems to overestimate energy demand in comparison with the outputs from the detailed model. This is more evident for high heating loads in residential buildings. At contrary, cooling loads are slightly underestimated along the whole range of results. In general terms, correlation is considered sufficient for all loads, reaching its peak in residential buildings. Due to the importance and prevalence of this typology, the overall results from the notional grid experiment can be considered as highly satisfactory.

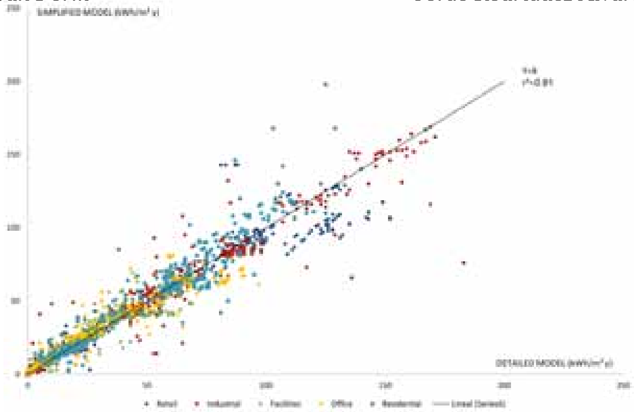


Fig.6-32 Scatter plot and correlation between results from simplified (notional grid) and detailed models in Climatelite

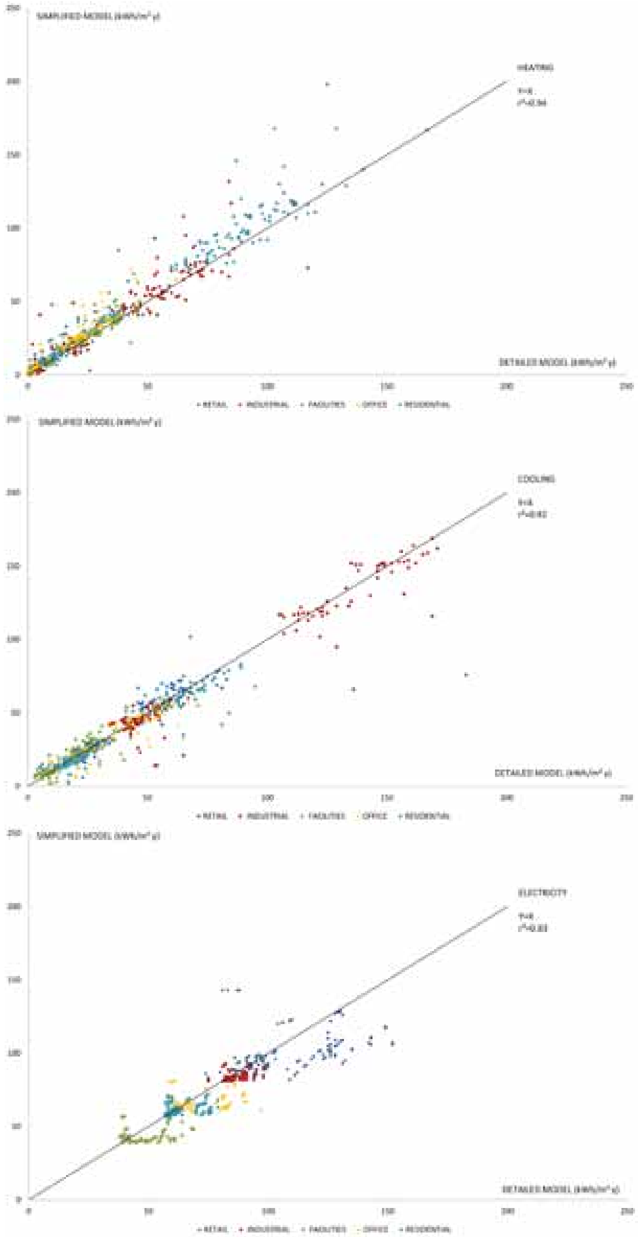


Fig.6-33 Scatter plots and correlation between results from simplified and detailed models in Climatelite for heating (top), cooling (center) and lighting (bottom)

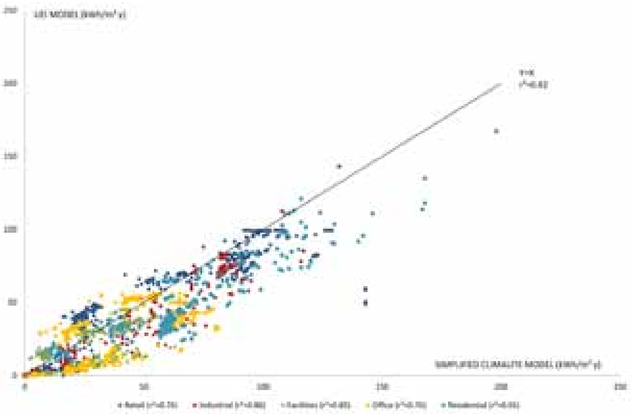


Fig.6-34 Scatter plots and correlation between results from simplified models in UEI and Climatelite

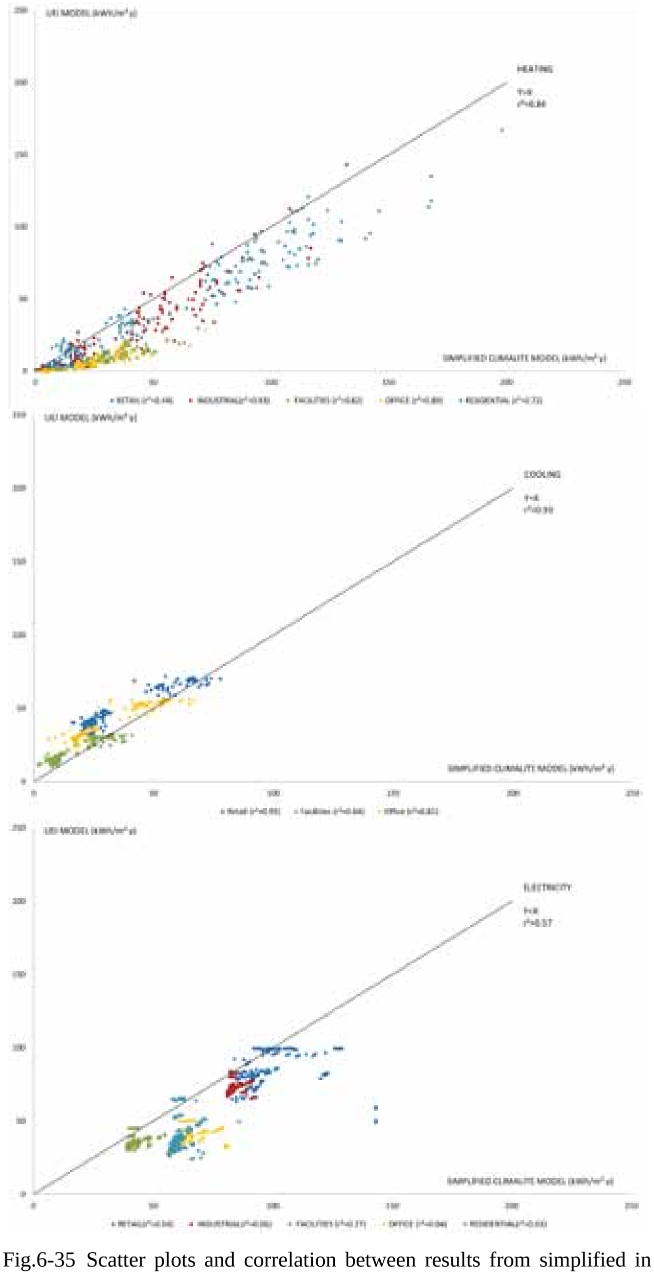


Fig.6-35 Scatter plots and correlation between results from simplified in UEI and Climatelite for heating (top), cooling (center) and lighting (bottom)

6.6.4. Validation II: UEI vs. Climatelite simplified model (using notional grid)

The next step in the validation process consisted on the comparison between the results obtained with the UEI tool against Climatelite outputs. To keep consistency, the same weather data was used in the simulations performed with both tools. Building specifications, materials and schedules in UEI replicated default values in Climatelite, which were defined in Climatelite's GUI and supporting documents. UEI models are simplified versions by definition, as the tool operates using the notional grid approach. The first correlation analysis was performed between UEI and simplified models in Climatelite, so that the urban morphology was the same in both models. As expected, the correlation between the outputs from the two different tools was not as high as in the previous tests. However, it still reached strong values (r^2=0.82), with UEI slightly underestimating energy demand in genera (fig. 6-34). Focusing on energy loads separately, some points of divergence between the models became apparent, especially for electricity loads (fig. 6-35):

- The clustering of **electricity outputs** is more accused in the UEI than in Climalite simplified model. For some building types the prediction of electricity was particularly weak (residential electric load, r^2=0.03). It was somehow expected, the algorithms and assumptions to calculate lighting in the UEI model were not based in Climatelite parameters because they could not be identified. Moreover, UEI only accounts for lighting energy whereas Climatelite also considers appliances and other electronic devices. Therefore, the discrepancy between values from the two models can be partly explained by differences in the input parameters. Notwithstanding these discrepancies, values do follow a similar trend and high loads in Climatelite usually correspond with high loads in UEI.
- Regarding **heating loads**, they seem slightly undervalued in UEI for all building types, although the correlation is relatively strong for most of them. Retail buildings have the lowest correlation coefficient (r^2=0.44) followed by residential buildings at a considerable distance (r^2=0.72).
- Finally, **cooling loads** appear to be overestimated in UEI in relation with Climatelite but the correspondence between them is still strong

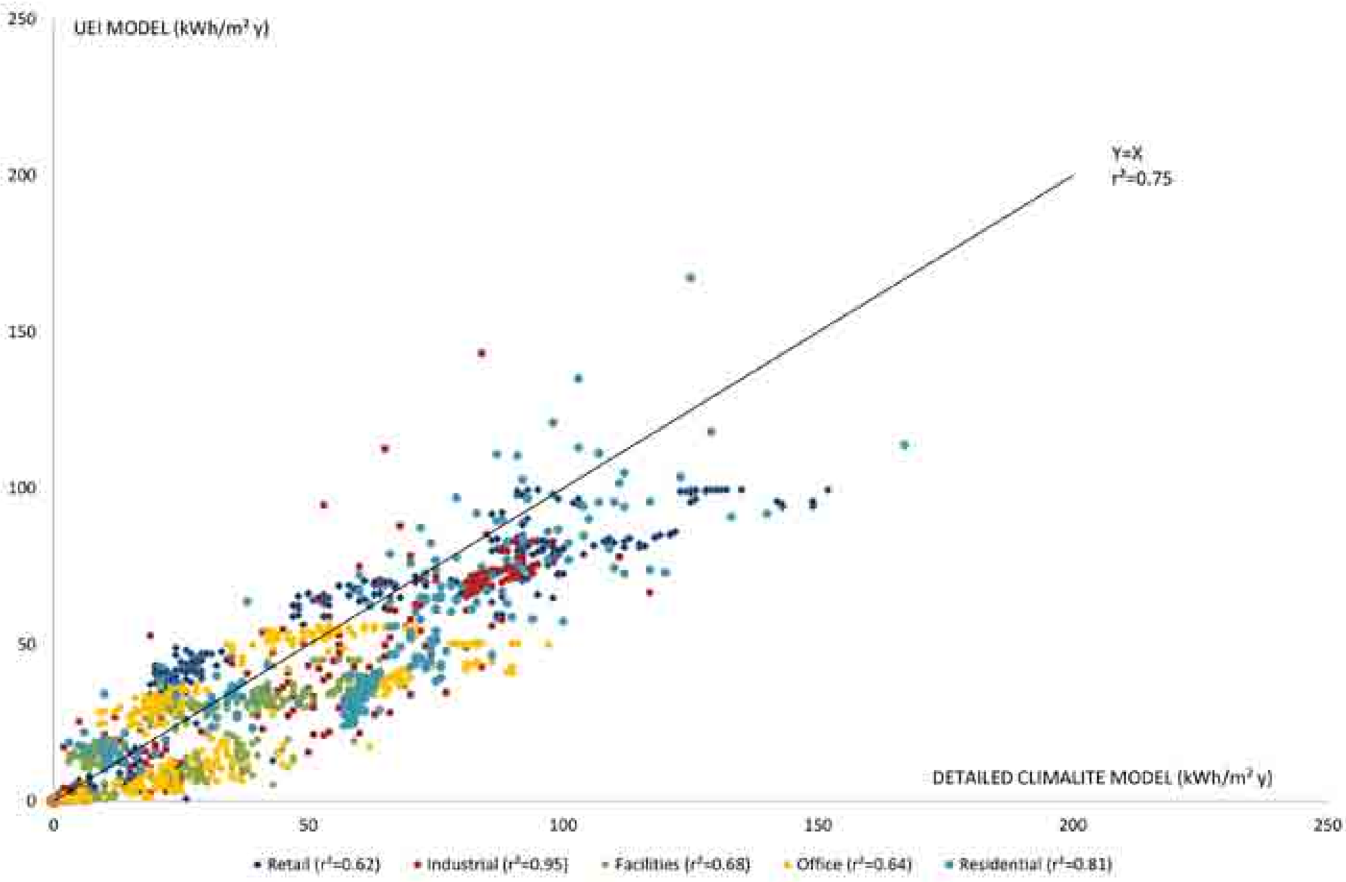


Fig.6-36 Scatter plot and correlation between results from simplified models in UEI and detailed models in Climatelite

6.6.5 Validation III: UEI vs. Climatelite detailed model

The last correlation analysis was performed to test the correspondence between UEI results and detailed models in Climatelite (fig. 6-36). This is the ultimate validation to test the accuracy of the proposed application when compared against traditional methods. The overall correlation (r^2=0.75) suggests that both approaches have a similar potential to reveal trends in energy consumption associated to urban morphology. Neither of them aims for precision but for relative outputs that require an educated interpretation. In this sense, the possibility of obtaining contradictory results from both models is small. Obviously, detailed models offer a higher degree of reliability, since every building has been drawn in detail. However, if time and resources are important factors, the advantage of UEI is overwhelming. In addition, the workflow of UEI has a great potential for further development, calibration and integration in GIS tools.

6.7. Typological studies

One of the possible applications of the UEI is the study of urban form in relation with buildings' energy performance. Studies on this subject are typically based on parametric analysis in which the effects from urban parameters are evaluated one at a time. The impacts of different orientations, urban canyon or building depth are tested in iterative simulations, in which a single parameter is varied while the rest of the model remains fixed. This process is time consuming and the results are normally circumscribed to the specific case that is being assessed. In this study, 28 samples were modeled in Climatelite (fig. 6-31) software tool for the validation and calibration of UEI. The results of those simulations are now available to conduct morphological studies. In contrast with Climatelite or traditional energy simulation tools, the Urban Energy Index allows for synthetic analysis, based on input parameters that can, additionally, be interconnected. The introduction of mathematical urban parameters instead of the geometric arrangement of buildings brings the model

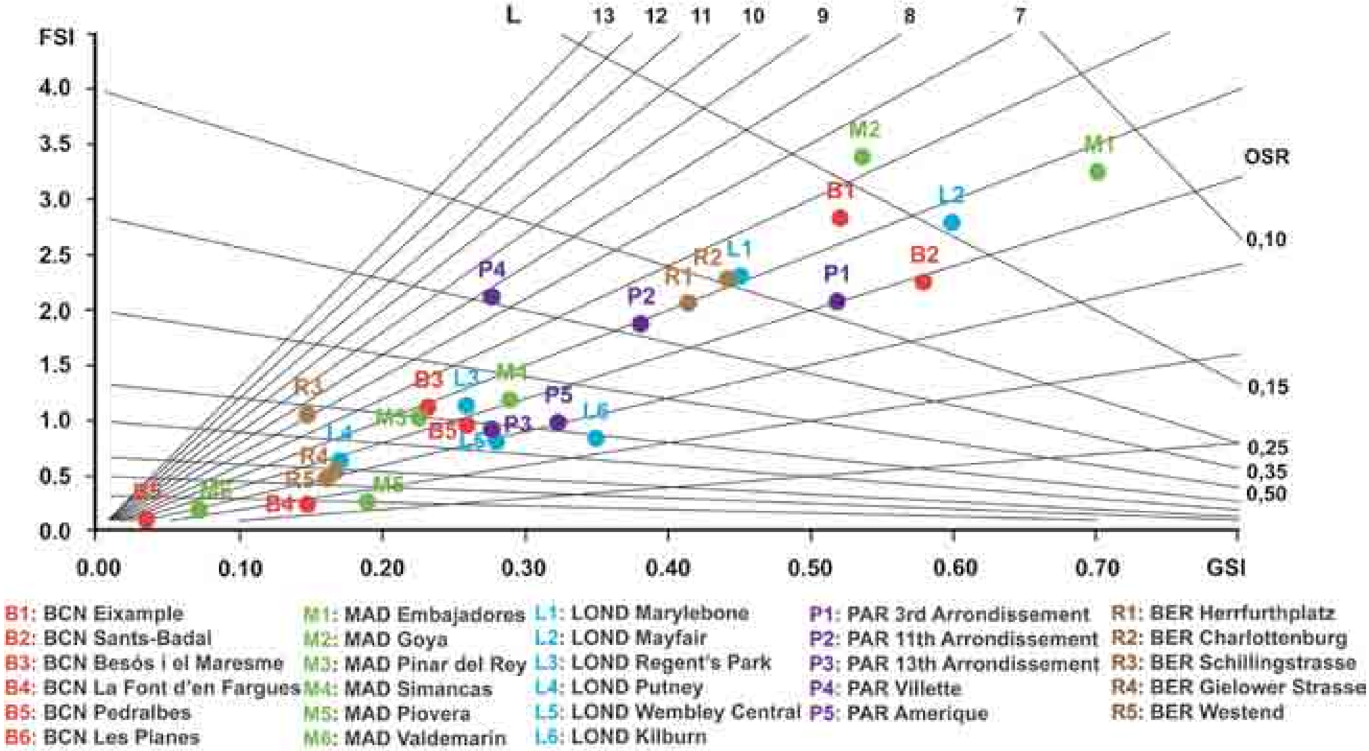


Fig.6-37 Urban samples in Spacemate diagram

to the same level of abstraction that urban planning often requires. In both strategic planning and in the early stages of development planning, information about the final arrangement of buildings is not available. The plan merely establishes abstract values for coverage (GSI) or building intensity (FSI) that will not be transformed into a detailed design until later stages. Knowledge on the consequences of planning prescriptions at early stages would provide planners and stakeholders with further elements for decision making.

The twenty eight urban samples that were modeled in Climatelite and UEI for the validation process were used to perform a preliminary analysis on urban morphology and energy behavior. Results from Climatelite were used in this analysis to perform a conventional energy study. In a following stage, the capability of UEI will be used to complement the outcomes from that research. The same assumptions and default parameters detailed in the previous section were applied to the simulation settings:

- Each sample was modeled for its own climate and the other four climates considered in the study. Each climate is associated to the corresponding latitude. For a better visualization only four climates were plotted in the graphs.
- Internal conditions, thermal capacity, surface albedo, window ratio, average floor height and the U-value of materials were fixed in all samples and for each building type.
- The variables to evaluate were: Ground Space Index (GSI), Floor Space Index (FSI) and Compactness (Comp). They were different and specific of each urban sample.
- Each simulation provided references for heating, lighting and cooling associated to each urban form and five building types: retail, industrial, facilities, office and residential.

The analysis of all these variables resulted in a matrix composed of 45 elements (5 building types x 3 loads x 3 urban parameters). The complexity of such framework suggests that before moving to a comprehensive investigation of all values, the study should be narrowed down. It initially focused on the impact of the three urban parameters (FSI, GSI, and Compactness) in the heating and lighting demand from domestic buildings. If results from this analysis were convincing, the same method could be followed to evaluate other building types, otherwise a different approach should be taken. The cases were plotted in Spacemate diagram [74](fig. 6-37) for an intuitive visualization of the morphological range that was represented in the collection. It can be noticed how the distribution in the two main axis of the diagram is rather constant. GSI values range from 0.04 to 0.7m²/m² whereas FSI ranges from 0.1 to 3.5m²/m² approximately. In addition,

74 Berghauser Pont & Haupt, 2010

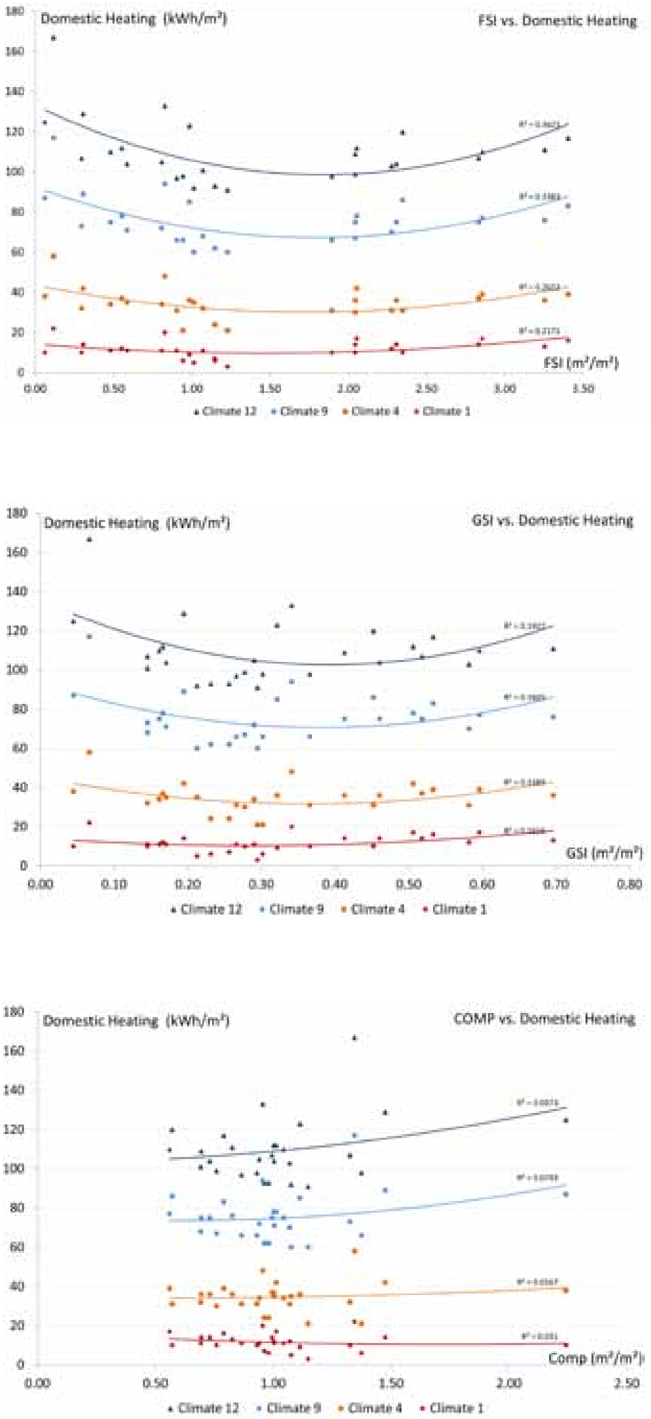


Fig.6-38 Domestic Heating versus FSI (top), GSI (center) and Compactness (bottom)

the Spacemate diagram allows a visual estimation of average building height based on these two parameters (lines L). Many samples are clustered around the line that indicates a mean height of four floors, although this is average height can be achieved in different ways: with high density and few open spaces or with lower values of both FSI and GSI. Although compactness is not represented in the Spacemate diagram, it can be pointed that samples include values from around 0.6 (very compact) to 2.20 (shallow and exposed buildings).

6.7.1. Urban morphology and Domestic Heating

In a different sequence of diagrams, urban samples were distributed by their respective FSI to compare the effect of this parameter in domestic heating (fig. 6-38). Although the correlation between both variables is, in general, rather weak, the dispersal graph shows a parabolic behavior of heating load in relation with the FSI. In the first section, the relation is inverse, heating load decreases with higher FSI. There is a turning point though, around FSI=1.5 m²/m², in which this trend changes. From that value onwards, the heating load increases with FSI, although at a less pronounced rate than in the initial section. The greater obstruction that results from intensely built areas is a plausible explanation for this change of trend. Less solar energy is available to displace conventional heating in dense urban fabrics. Beyond the turning point, the absence of solar gains apparently outweighs the reduction in heat losses associated with the reduced exposure of dense areas. This pattern is notably more marked in cold climates. In fact, in Mediterranean climates the variations are barely noticeable.

Similar patterns, although less pronounced, can be indentified from the analysis between heating load and GSI. The energy demand reduces when moving from very low coverage to intermediate values. From GSI=0.3, higher coverage induces an energy penalty which is, like in the previous case, more important for colder climates.

The analysis of compactness reveals a weaker correlation with the heating load. This is rather counterintuitive, both building thermodynamics and previous research[75] have pointed to compactness as a critical parameter in energy performance. The patterns, which can be faintly identified in the dispersal graph, indicate that heating load are greater when the ratio between envelope to floor area is higher (i.e high compactness ratio and therefore more exposure). This is more evident for northern latitudes as in southern climates urban form seems to have little impact in the heating load anyway.

75 LSE Cities & Eifer, 2010

6.7.2. Urban morphology and Domestic Cooling

As all values from Climatelite analysis, domestic cooling should be taken only as a reference rather than as predicted actual energy demand. But in this case, it must be emphasized even further, because buildings were modeled without any consideration for solar control, something that would be unlikely in practice. Moreover, industrial and domestic buildings were not set to calculate cooling loads with the default specifications of Climatelite. Modifications to the initial parameters were done in order to obtain a cooling reference value for these two building types. With these considerations in mind, the analysis of cooling patterns indicates an inverse relation with building intensity. The estimated load decreases when both FSI and GSI rise, influenced by the obstruction and reduced solar penetration into the building fabric. However, the model does not consider the symbiotic relation between buildings and outdoor environment. Neither does it account for heat island effect produced by taller and closer buildings. All these factors need to be considered before extracting any conclusions about the effects of urban densification. On the other side, the comparison between cooling and compactness ratio shows that exposure in warm climates may lead to an increase in internal temperatures and, consequently, additional need for cooling.

6.7.3 Urban morphology and Domestic Electricity (light and appliances)

Unlike heating loads, the electric demand barely varies across climates. Daylight hours seem to balance along the year and daylight availability is outweighed by urban morphology, the effect of non passive zones and the fixed load from appliances. Correlations are stronger than for heating loads in the three urban variables being studied. FSI and GSI present similar correlation factors ($r^2 \approx 0.75$) while Compactness shows a weaker consistency ($r^2 \approx 0.35$).

The electric load tends to increase evenly with density and ground coverage, while it diminishes when the compactness ratio increases. The obstructions created by adjacent buildings, and the proximity with them, reduce daylight availability, especially in lower floors. In contrast, shallow buildings, with high exposure, have a greater capacity to capture external daylight. This ability can be however undermined by other factors, such as orientation or obstruction, as it is suggested by the weak correlation showed in fig. 6-40.

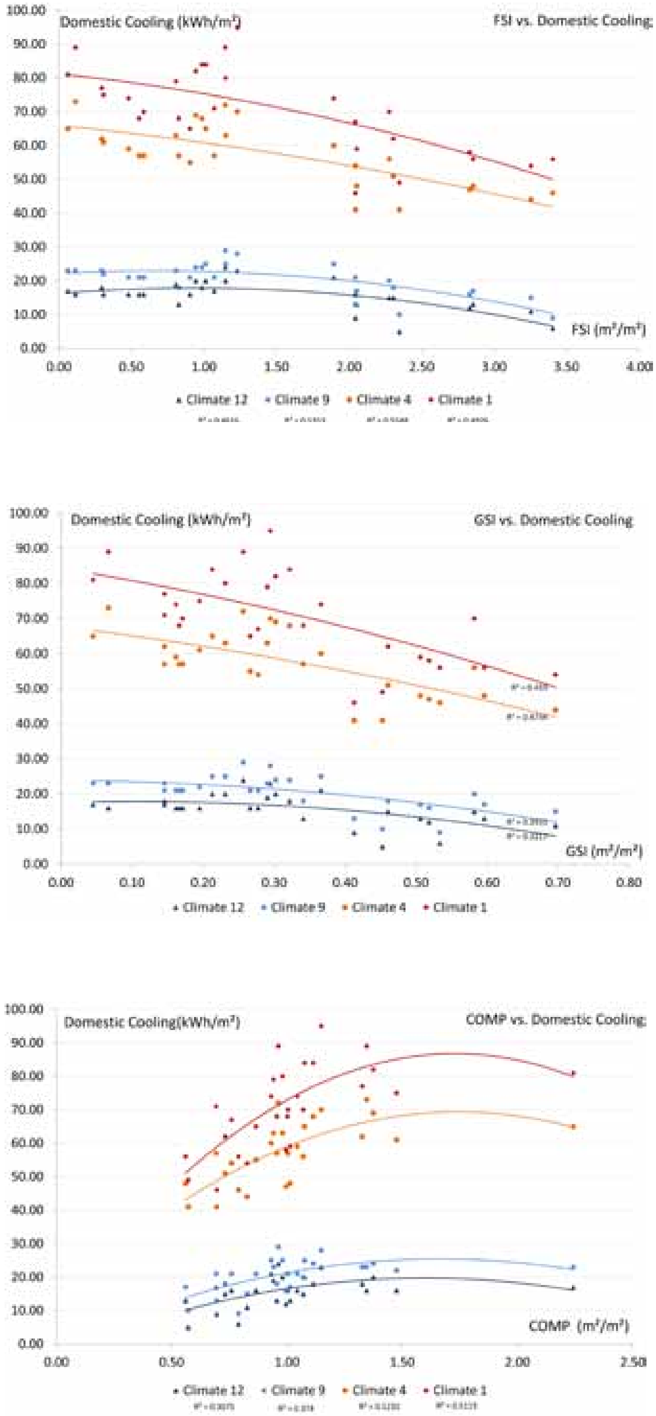


Fig.6-39 Domestic Cooling versus FSI (top), GSI (center) and Compactness (bottom)

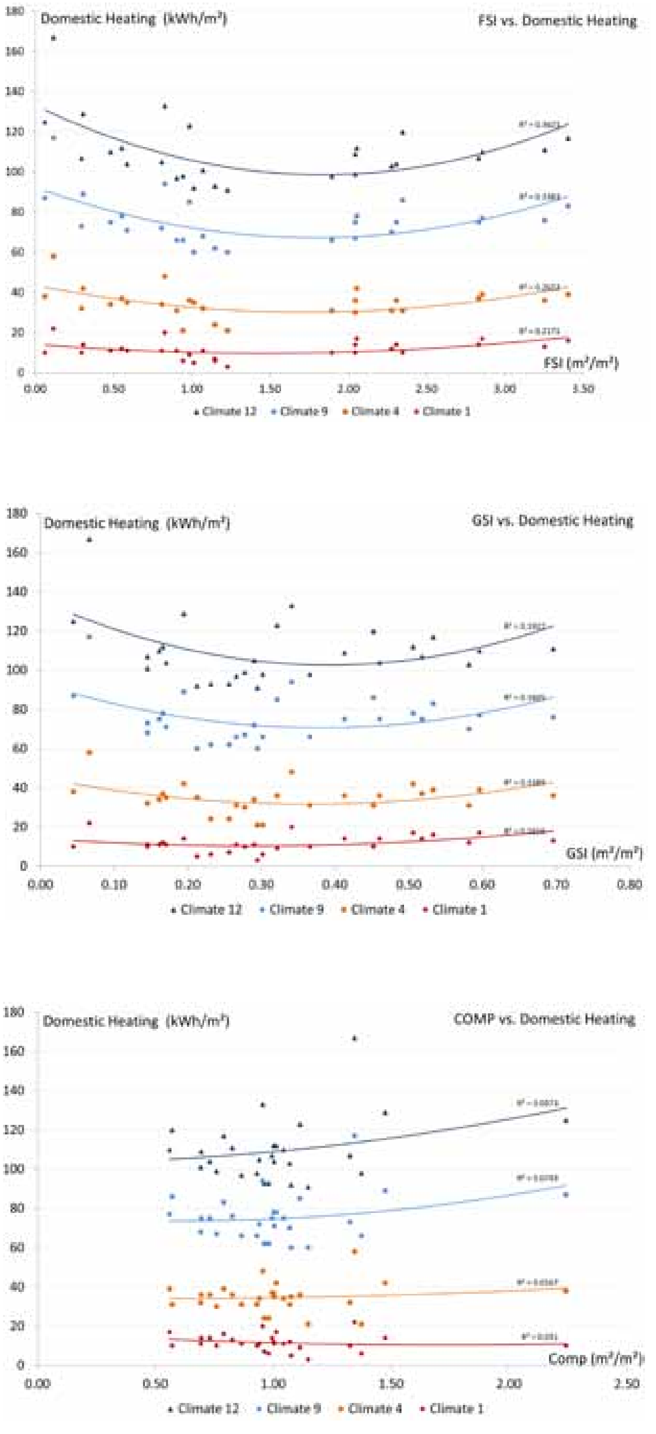


Fig.6-40 Domestic Electricity versus FSI (top), GSI (center) and Compactness (bottom)

6.7.4. Urban typologies and energy efficiency

The Climatelite analysis picked up from the simulations that had been performed for the UEI validation to indentify patterns between environmental behavior and urban typologies. This approach has the advantage of using real cases, which can be visualized and associated with urban experiences. It is easier to understand the implications of urban parameters when they are embodied in places that can be visited, walked and lived. However, on the other hand, there is a relatively narrow limit for the exploration in actual samples. They represent current standards but they cannot depict prospective or speculative urban arrangements. This can be solved by modeling abstract forms, defined for the purpose of the study. It is a conventional strategy that has been broadly used in urban environmental research. However, if the selection of scenarios is not based on clear-cut criteria, some typical issues shall appear: redundant analysis, inadequate ranges or parametric steps, meaningless scenario definition, inability to extrapolate, unmanageable number of cases, etc... The extrapolation from a discrete study into a continuous model requires a sufficient number of samples to represent the parametric variations to be analyzed. This may not be possible using real cases and it shall require a considerable modeling and simulation effort to design, represent and assess multiple abstract scenarios.

The energy evaluation of the urban form is performed with a purpose: to determine whether a specific configuration enhances low energy performance in buildings. The typological analysis conducted so far has shown general patterns that are rather inconclusive. In the view of these results, several questions arise:

- In terms of energy, is it even possible to define a good urban form? Which indicators can better define goodness?
- How would the samples rank in a direct comparative analysis? Is there an urban form that performs the best across all climates or are good forms climate specific?
- How can the values obtained in the simulations be used to compare overall performance (including heating, lighting and cooling)?
- How can they be related to benchmarks and references?

Fig. 6-41 shows the urban samples distributed along the spacemate diagram, together with their corresponding domestic heat load for Climate 12. As suggested by previous analysis, high energy values tend to be located at the extremes of both axes, whereas the optimum performance is to be found in intermediate values (GSI between 0.2 to 0.3 and FSI around 1 m²/m²). A range of urban typologies composed of compact blocks and open layouts, such as those of Besós in Barcelona, Pinar del Rey in Madrid, La Villette in Paris, Regent's Park State in London or Schillingstrasse in Berlin, seem to perform well under cold conditions. However, this

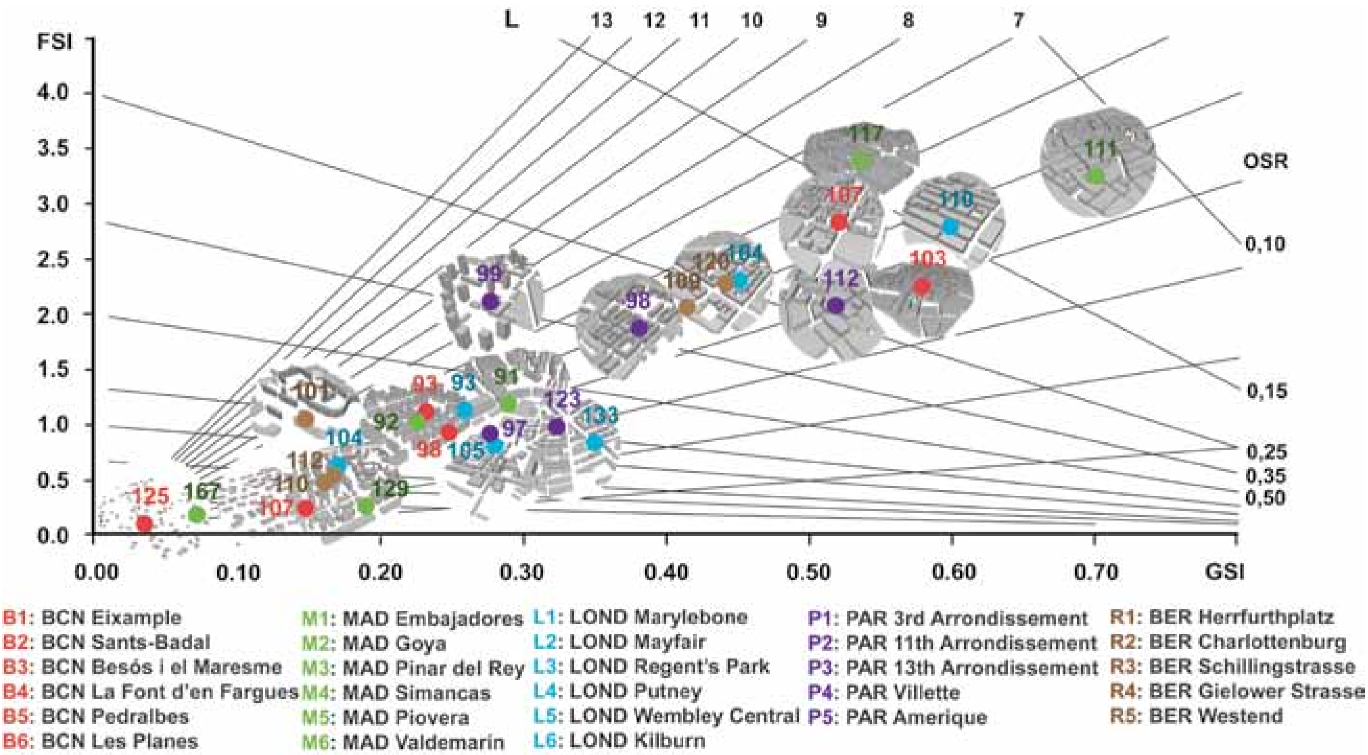


Fig.6-41 Urban samples and domestic heat load reference for Climate 12

is only a partial view as it represents a specific energy use (heating) for a specific building type (housing) and a specific climate (climate 12, Northern Europe). Urban typologies may not be so efficient for other energy uses, building types or climates, as it was illustrated by figures 6-38 to 6-39. The consistency of energy efficient urban forms across these factors will be analyzed in a subsequent research stage.

Normalization and typological matrix

In order to establish more realistic energy values, the results from Climatelite simulations were used as weighting factors and applied on existing benchmarks. For every climate and energy use, the average from all results was found and every single outcome was transformed into a percentage value of that average. Therefore, the average result became 100 and all other results were represented as:

$$\mathbf{W_f = 100 \times (E_n / E_{avg})}$$

Where, W_f = Weighting energy factor

E_n = Energy estimate from simulation

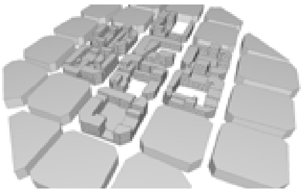
E_{avg} = Average of energy estimates for specific building type, climate and energy use

Energy consumption benchmarks were then identified for the different locations from existing literature and surveys. These references were multiplied by the weighting factor of each urban form so that values associated to each sample became closer to what could be expected in reality. The same procedure was repeated for the five climatic zones and for heating, electricity and appliances and cooling in domestic buildings. No investigation in further building types is reported at this point so as to avoid excessive repetition. Moreover, cooling loads were removed in the analysis of climates 9, 11 and 12 since it was considered they were not representative as only poor building design would induce cooling load in such conditions[76]. Energy demand that is not directly affected by urban or building form was not considered either. This includes cooking and domestic hot water. A graphic matrix of urban typologies was created to display the results in each city (fig. 6-42). This allows a quick identification of performance trends associated to urban morphology in each climate. The total primary energy was then calculated. Average transformation factors were applied for heating and electricity to allow the summing up of all loads. A second matrix (fig. 6-43) was drawn up with the total primary energy consumption of each urban sample.

76 Recent empirical research has found overheated dwellings in London as result of over-insulation, excessive airtightness and poor ventilation. However, simple environmental strategies can prevent cooling demand in these locations.

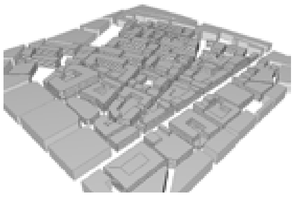
BARCELONA
C1, 40º N

Eixample



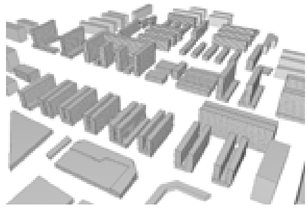
46 kWh/m²
40 kWh/m²
10 kWh/m²

Sants-Badal



34 kWh/m²
39 kWh/m²
12 kWh/m²

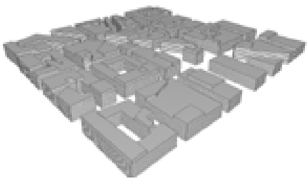
El Besós i el Maresme



34 kWh/m²
32 kWh/m²
14 kWh/m²

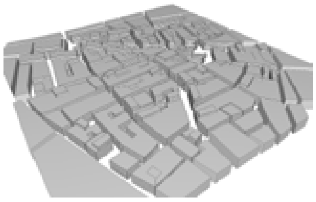
MADRID
C4, 41º N

Goya



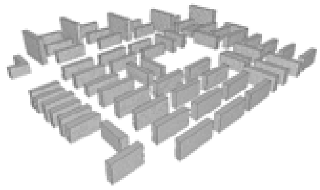
72 kWh/m²
41 kWh/m²
14 kWh/m²

Embajadores



67 kWh/m²
42 kWh/m²
13 kWh/m²

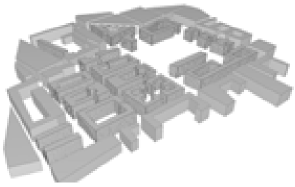
Pinar del Rey



65 kWh/m²
32 kWh/m²
19 kWh/m²

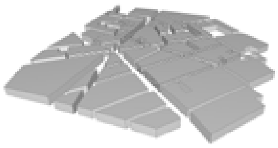
PARIS
C9, 48º N

11th Arrondissement



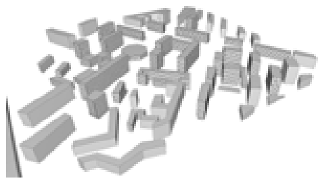
184 kWh/m²
32 kWh/m²

3rd Arrondissement



217 kWh/m²
41 kWh/m²

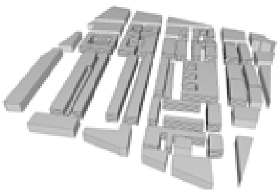
13th Arrondissement



184 kWh/m²
33 kWh/m²

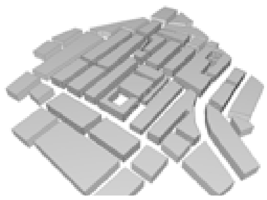
LONDON
C11, 51º N

Marylebone



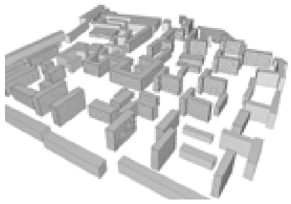
147 kWh/m²
38 kWh/m²

Mayfair



151 kWh/m²
40 kWh/m²

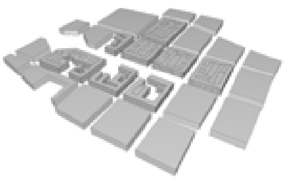
Regent's Park



117 kWh/m²
32 kWh/m²

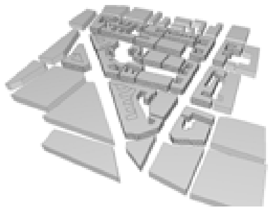
BERLIN
C12, 52º N

Herrfurthplatz



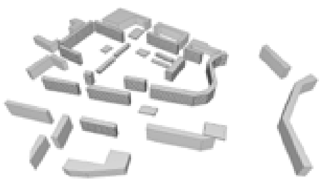
180 kWh/m²
39 kWh/m²

Charlottenburg



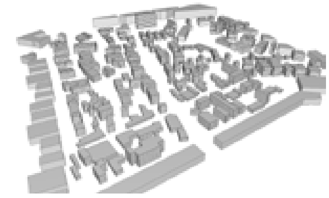
198 kWh/m²
40 kWh/m²

Schillingstrasse



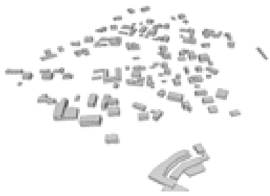
167 kWh/m²
33 kWh/m²

La Font d'en Fargues



37 kWh/m^2
33 kWh/m^2
14 kWh/m^2

Pedralbes



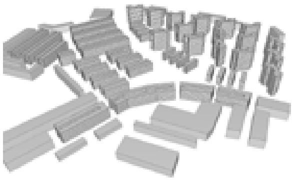
37 kWh/m^2
33 kWh/m^2
13 kWh/m^2

Les Planes

37 kWh/m^2
32 kWh/m^2
14 kWh/m^2

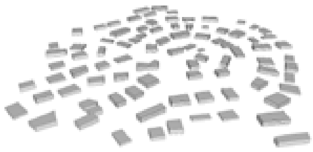
HEATING
ELEC & APP
COOLING

Simancas



39 kWh/m^2
32 kWh/m^2
21 kWh/m^2

Piovera



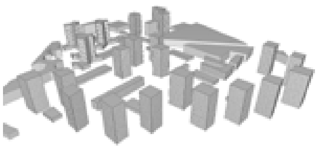
78 kWh/m^2
32 kWh/m^2
18 kWh/m^2

Valdemarín

107 kWh/m^2
32 kWh/m^2
22 kWh/m^2

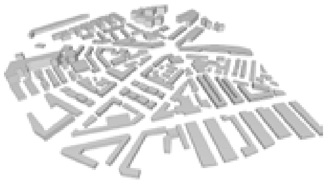
HEATING
ELEC & APP
COOLING

La Villette



186 kWh/m^2
34 kWh/m^2

Amérique



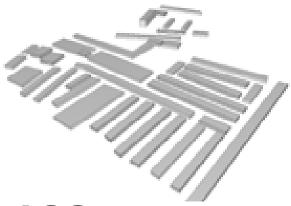
237 kWh/m^2
32 kWh/m^2

HEATING
ELEC & APP

Putney

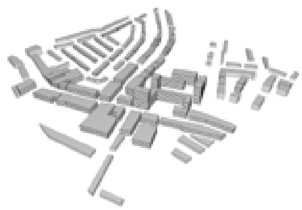
141 kWh/m^2
32 kWh/m^2

Kilburn



188 kWh/m^2
34 kWh/m^2

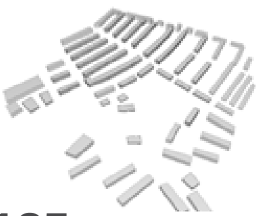
Wembley



144 kWh/m^2
33 kWh/m^2

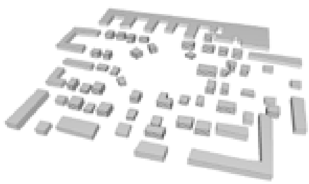
HEATING
ELEC & APP

Gielower



185 kWh/m^2
32 kWh/m^2

Westend



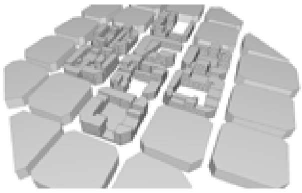
182 kWh/m^2
33 kWh/m^2

HEATING
ELEC & APP

Fig. 6-42 DELIVERED ENERGY BY END USE

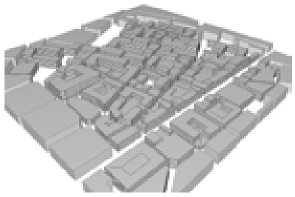
BARCELONA
C1, 40º N

Eixample



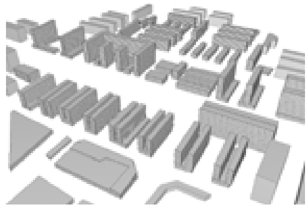
169 kWh/m²

Sants-Badal



157 kWh/m²

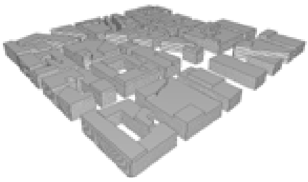
El Besós i el Maresme



144 kWh/m²

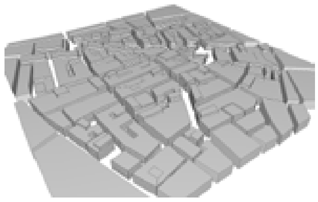
MADRID
C4, 41º N

Goya



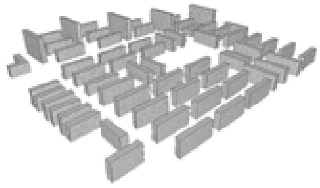
213 kWh/m²

Embajadores



206 kWh/m²

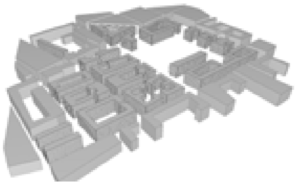
Pinar del Rey



194 kWh/m²

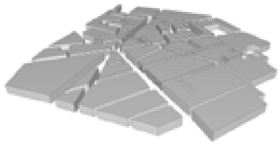
PARIS
C9, 48º N

11th Arrondissement



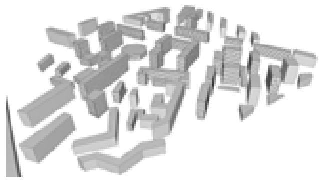
295 kWh/m²

3rd Arrondissement



355 kWh/m²

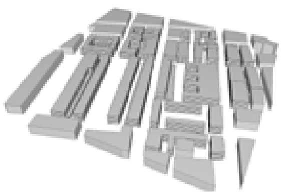
13th Arrondissement



297 kWh/m²

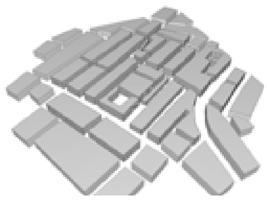
LONDON
C11, 51º N

Marylebone



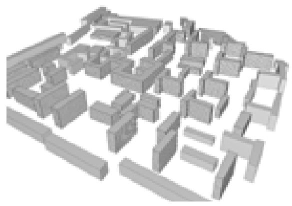
265 kWh/m²

Mayfair



273 kWh/m²

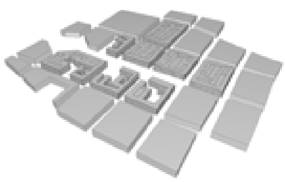
Regent’s Park



215 kWh/m²

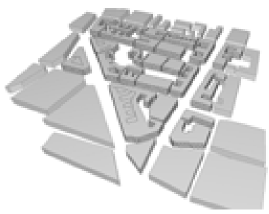
BERLIN
C12, 52º N

Herrfurthplatz



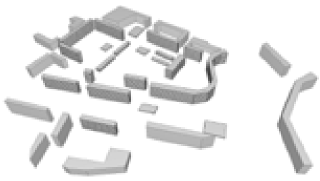
306 kWh/m²

Charlottenburg



329 kWh/m²

Schillingstrasse



276 kWh/m²

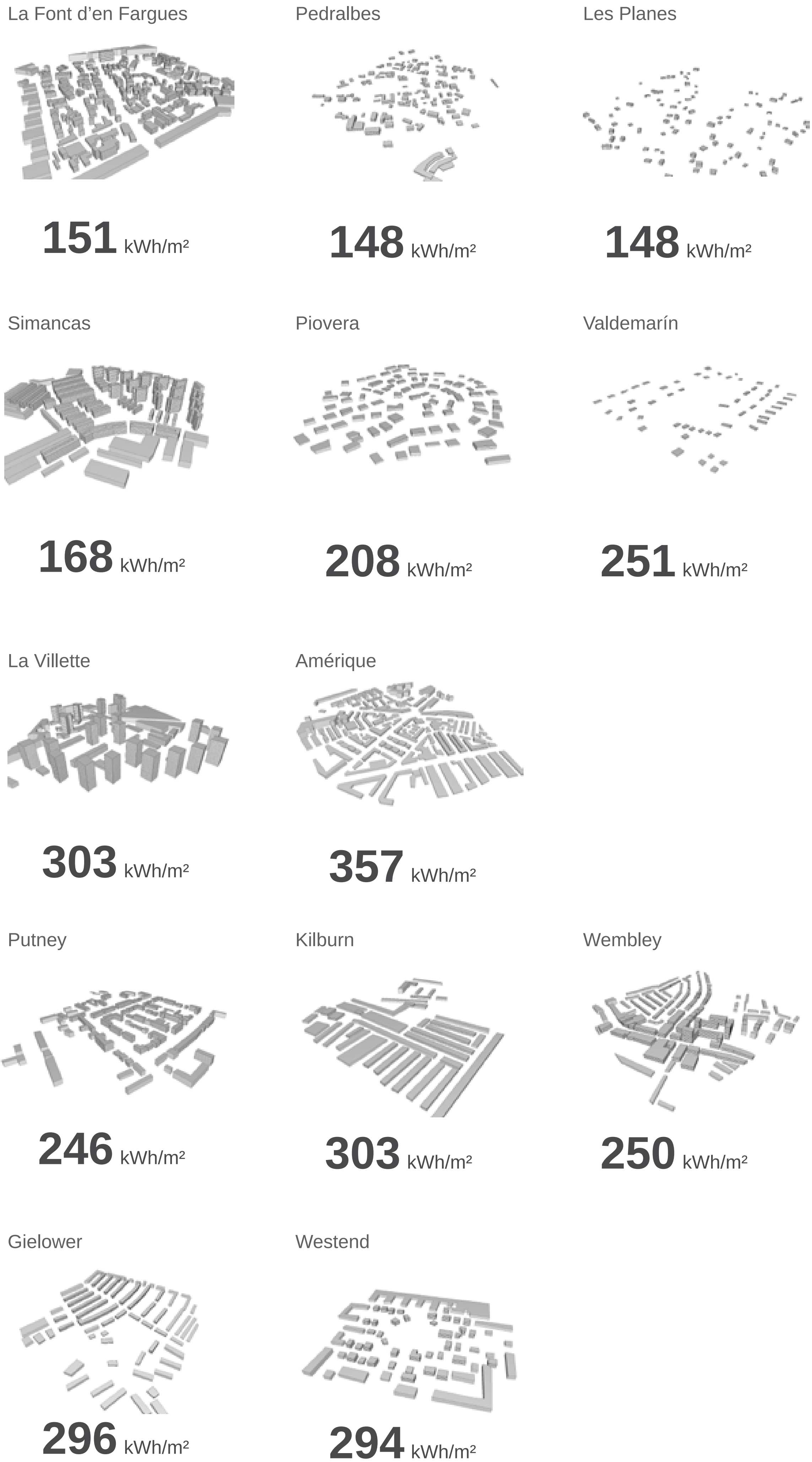
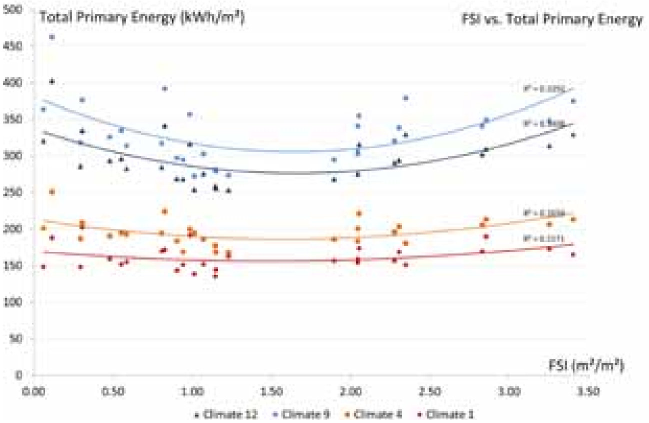
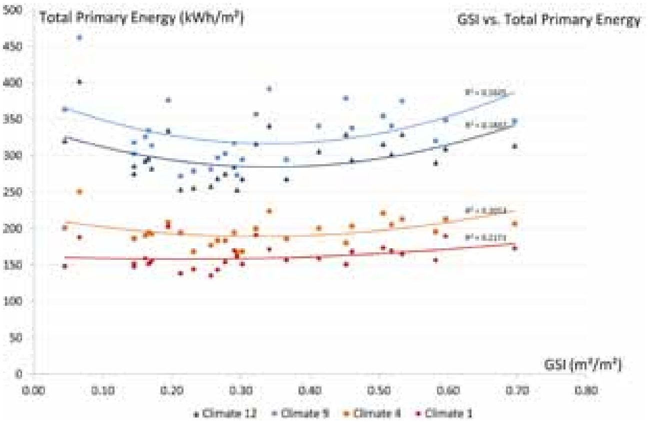


Fig. 6-43 TOTAL PRIMARY ENERGY





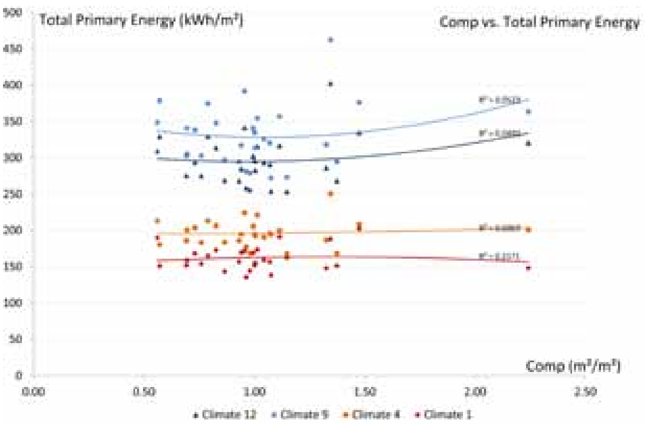


Fig.6-44 Total primary energy load versus FSI (top) GSI (center) and Compactness (bottom)

Both matrices illustrate the increasing influence of urban form in heating and cooling when moving from southern mild climates to northern colder ones. In contrast, electricity only varies within a small range and fluctuations responds more to the urban layout than to climatic conditions. The display of energy breakdowns emphasizes the importance of heating in all cities, although the proportion in relation to the total load spans from around 40% in Barcelona to 80% in Paris, London or Berlin[77]. Consequently, energy related policies should establish different priorities and targets for each location. In northern latitudes, reducing heating demand would deliver substantial benefits in terms of overall energy savings, whereas in Mediterranean climates, preventing overheating and the enhancement of daylight may become as significant as the heating load. Indeed, due to current increase of insulation standards, heat loads are being significantly reduced in new and refurbished buildings. It has a double consequence: On the one hand, large and exposed envelopes are less penalized. Therefore, the performance of flats and detached dwellings may not differ so significantly. On the other hand, compactness tends to conflict with daylight savings. In cold climates, a compact form could be justified on the grounds of heat conservation. If heat loss is diminished by improving the envelope's insulation, the enhancement of daylight could be prioritized over compactness, without compromising heating demand. It drastically affects design criteria.

Looking at total energy demand, it can be noticed how low dense developments in Barcelona perform very similar to the most efficient typologies. Urban building policies could be based on other aspects than energy, since a good performance can be easily achieved by almost any urban typology. The efficiency of the network or the costs of mobility were not considered in this analysis. In other cities, differences are greater and the open block is confirmed as the most energy efficient typology.

Going back to the abstract correlations between urban parameters and energy, the total primary demand is compared against the three main morpho-indicators (FSI, GSI and Compactness ratio) (fig. 6-44). The graphs resemble heating load correlations very closely. The main difference lays in the magnitudes of the vertical axis, which represents the sum of primary energy for heating, lighting and cooling (the former only for climates 1 and 4 only). It confirms the relative weight of lighting in cold climates. Although benefits from low FSI and GSI in the electric are significant, the overall demand gets the lowest peaks in moderately dense urban areas.

77 It can be noticed that energy values for Paris are higher than for London and Berlin. This is however consistent with energy benchmarks that were found in literature (Balaras et al 2000, Bell & Lowe 2000, Hens 2001, INEGA 2005) and used in combination with weighting factors.

6.7.5. Parametric studies

The previous analysis, carried out with Climatelite software tool, was based on the simulation of real samples: it was a **typological** study. It was based on a selection of case studies collected from real samples of urban fabric. The scope of parametric assessment is limited by this analytic technique as variables cannot be actually fixed or purposely modified in the pool of samples without distorting the representation of the urban type. As it has been explained in previous sections, using a conventional software (understood here as GUI software tools) for iterative simulations would be extremely time consuming. It requires pre-simulation calculations, data preparation, drawing process, actual simulation and results processing for each parametric combination. Since UEI only requires few input parameters, which are easily introduced into a spreadsheet, the analysis can be performed much faster, and parameters can be fixed or modified instantly. This second stage explores the capacity of UEI to undertake parametric assessments and to complement the outcomes from typological studies. The scope of the analysis is narrowed down to domestic buildings and heating demand. The main interest lies in the methodological development rather than in the exhaustive scrutiny of all operating factors. Further research can follow up to look deeper into multiple definition of building types, conditions and uses.

The first parametric analysis was devised to evaluate the influence of Compactness Ratio (envelope area divided by floor area) as this is a fundamental relation in the thermodynamic performance of buildings. In the iterative simulations, all parameters remained fixed, except the Compactness Ratio, which was modified in regular intervals, from 0.2 to 3 m²/m². The effects of variations were assessed for two climates: 1 (Barcelona) and 11 (London) that represented Southern and Northern zones respectively. The Floor Space Index was fixed, in this case, as 1.00m²/m² because it was a common value in the typological samples (30% of the samples were around that figure). Regarding the Ground Space Index, five alternative values were explored (0.2, 0.4, 0.6, 0.7, 0.8), although they all gave very similar results. It suggests that when Compactness and FSI are fixed, the influence of GSI is limited. In fact, looking at the plot of the results (fig.6-45) an almost linear correlation between compactness and heating demand is revealed. These results follow traditional wisdom and previous literature on building's environmental performance. The slope of the correlation is determined by weather conditions. In cold climates, energy demand increases substantially with exposure whereas in milder climates, the correspondence is not so pronounced. This was vaguely indicated in the typological analysis (fig. 6-33), but the interaction of the other variables seemed to prevent the emergence of clear patterns.

Having studied compactness, together with variations in GSI, the next parameter to be addressed was building intensity (Floor Space Index or FSI). Typological analysis had portrayed this relation with a parabolic profile, which suggested a decrease in heating load for the first intervals of FSI (up to FSI=1.5 m²/m² approximately) and an equally soft increase beyond the intermediate turning point. The

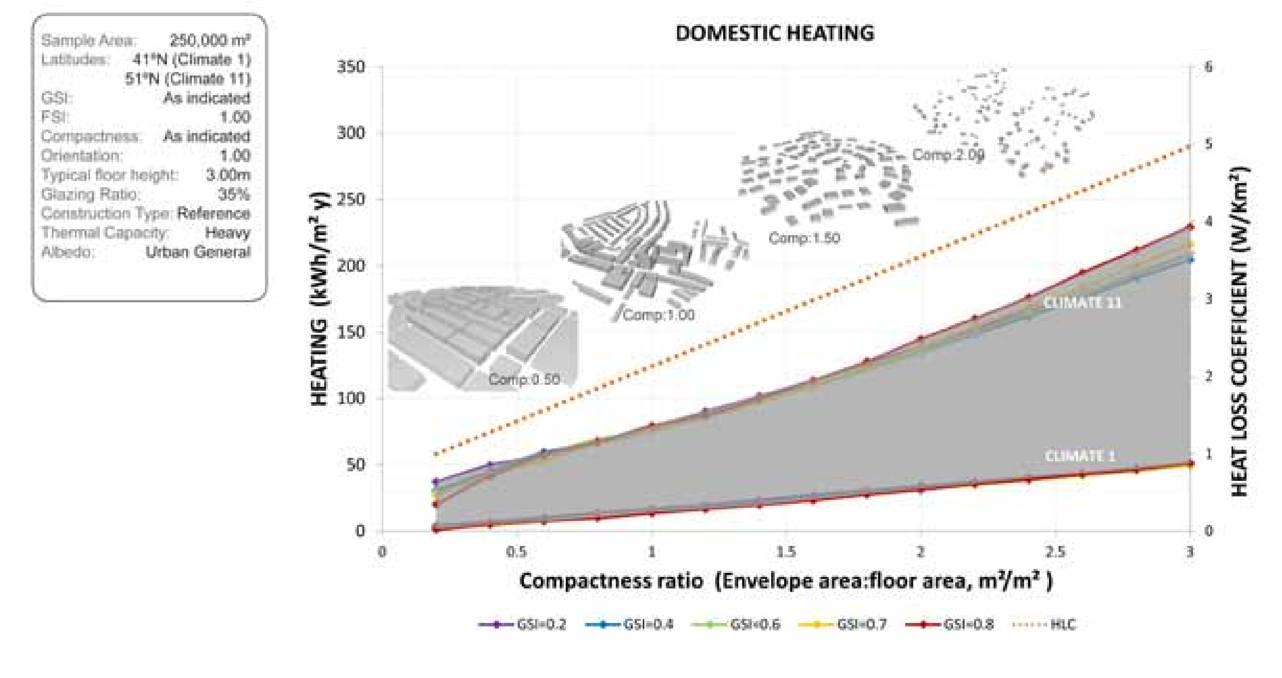


Fig.6-45 Domestic Heating versus Compactness Ratio and GSI

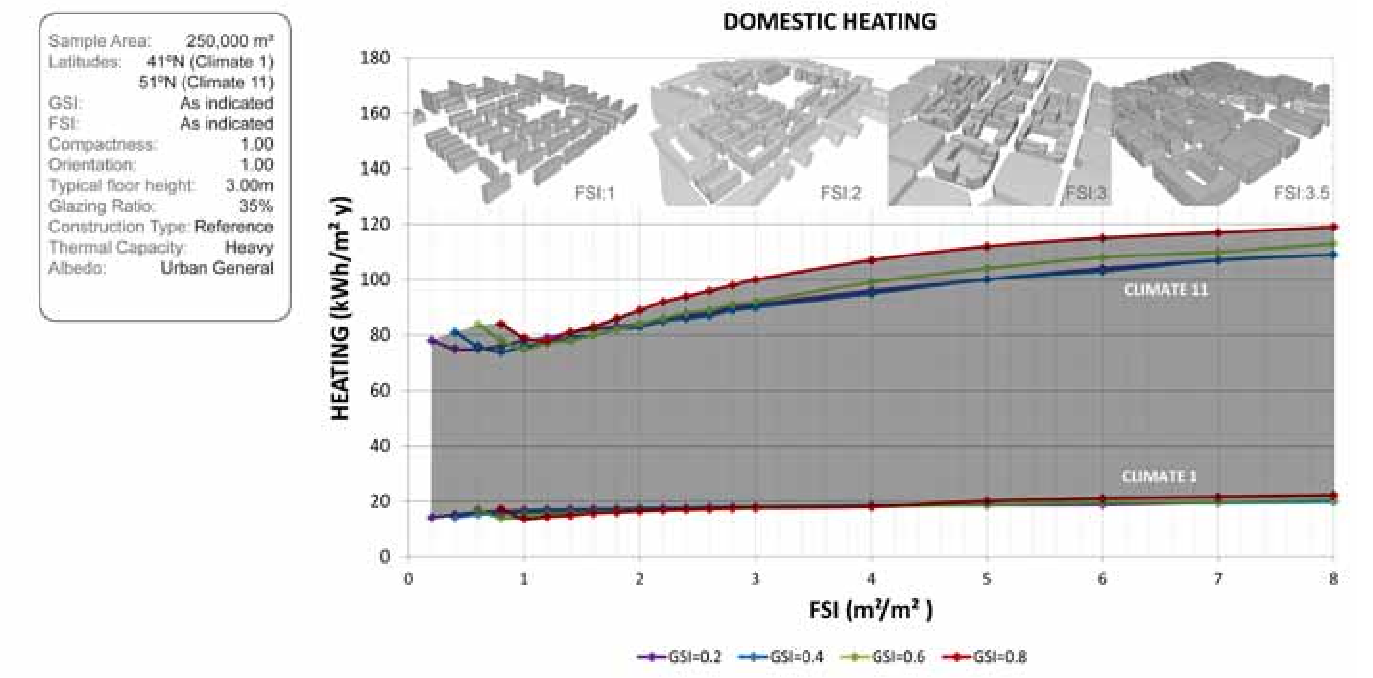


Fig.6-46 Domestic Heating versus FSI and GSI

nature of the analytic method limited the upper band of FSI to the maximum value among the available samples (FSI=3.5 m²/m²) and, therefore, the study of denser environments was prevented. For the parametric analysis of FSI, the Compactness Ratio was fixed as 1.00m²/m² and GSI was iteratively set as 0.2, 0.4, 0.6 and 0.8m²/m². All other parameters remained as in the previous study. The outcomes from the UEI calculations follow some of the trends identified in the typological analysis (fig. 6-46). The initial intervals of FSI are characterized by a decreasing trend that turns into a steady increase beyond FSI =1m²/m². One of the main insights in this analysis is that, since compactness is fixed, variations in heating demand cannot be explained as the effect of heat losses or envelope's exposure. In this case, the results show the isolated effect of increasing FSI in urban areas. Contrary to precedent research[78], higher building intensity has not, in itself, a diminishing effect on heating load. The obstruction caused by tall buildings prevents the effective use of solar gains. The initial decrease is, however, less intuitive. Scarcely built urban zones should enhance solar radiation availability, which is the main factor being affected by changes in the FSI. It may well respond to a flaw in the model approach that will be discussed in following paragraphs.

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Some considerations in parametric analysis

Typological analysis was constrained by the limited number of parametric combinations that were represented by the selected case studies, mainly because these were sourced from real urban structures. In parametric analysis a different issue may emerge. Even though any parametric combination can be theoretically calculated, some combinations are unrealistic and they cannot be associated with any real urban typology. Figure 6-47 illustrates some examples of urban typologies that result from these unlikely combinations. The two first cases were extracted from the FSI analysis, which included values up to 8m²/m² and the possibility of combining them with four GSI values, while compactness was fixed as 1 m²/m². A number of different arrangements are possible for each pair of FSI and GSI. However, when compactness is also determined, fewer arrangements can fulfill all three conditions. Values represented in figure 6-47 imply inconceivable physical layouts, such as urban canyons with streets of less than 2 meters wide or 40-storied buildings with a very shallow floor plan (12x12m). The third and fourth examples were taken from compactness analysis, which aimed to include a comprehensive range of variations with FSI being constant. Improbable combinations were found at both extremes of the range. Forcing compactness in areas with low building coverage (GSI) is a contradiction that

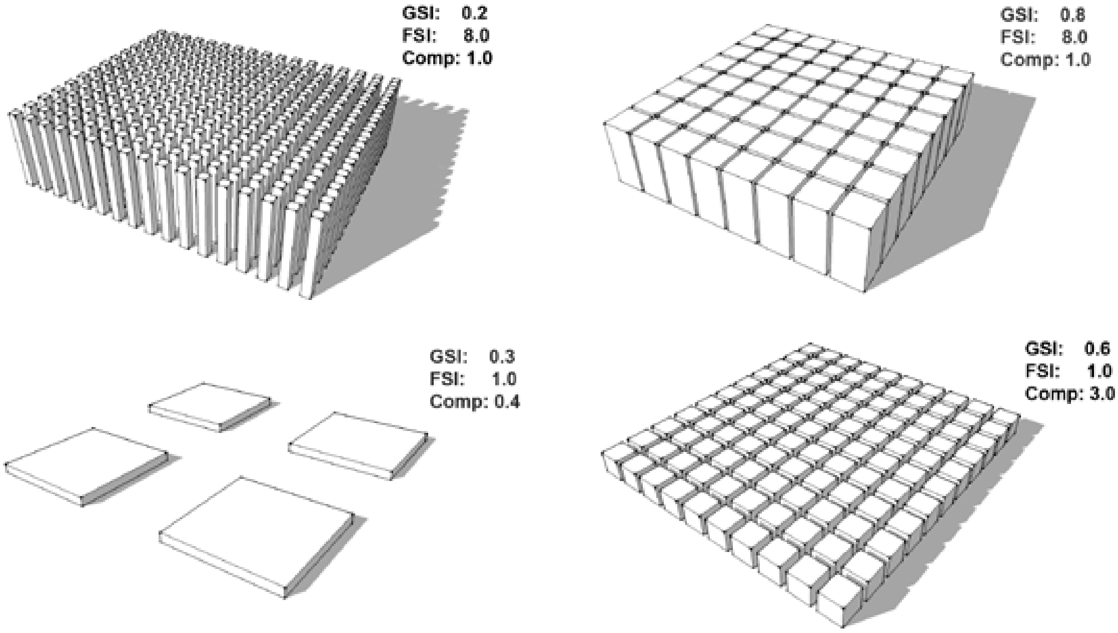


Fig.6-47 Examples of unrealistic combinations of urban parameters

results in deep buildings (100m x 100 m without courtyards) which can hardly accommodate residential uses. Similarly, high land coverage does not match well with large exposure as it gives low rise and shallow buildings with excessively narrow streets. The inclusion of unrealistic values is a typical flaw in parametric studies when correlations are generalized as continuous functions.

To overcome this situation, a different approach was conceived. It was presumed that compactness was a dependant value, determined by building intensity and/or coverage. The observation of the urban samples had shown how the Compactness Ratio tended to be higher in open areas than in the most intensely built zones. The plot of the compactness ratio of all samples against their respective FSI and GSI confirmed that the proportion between them was actually within a narrow band. Urban fabrics characterized by high FSI and GSI had usually a low Compactness Ratio. Several regression analysis were undertaken to find the best possible fit between these three parameters. The correlation function from the regression was used for the second set of parametric analysis. In this way, the input values were not totally independent as compactness was a function of GSI and FSI:

$$\textbf{Comp: } 1.2289 * 0.7507^{FSI} * 1.7235^{GSI} \qquad \text{[eq.2]}$$

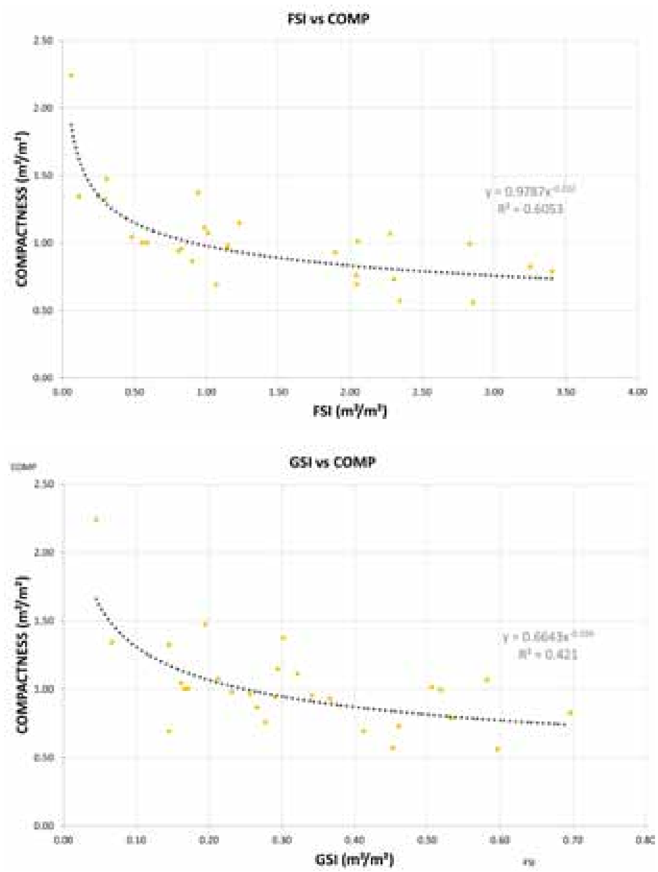


Fig.6-48 Correlations between FSI, GSI and Compactness in the 28 urban samples

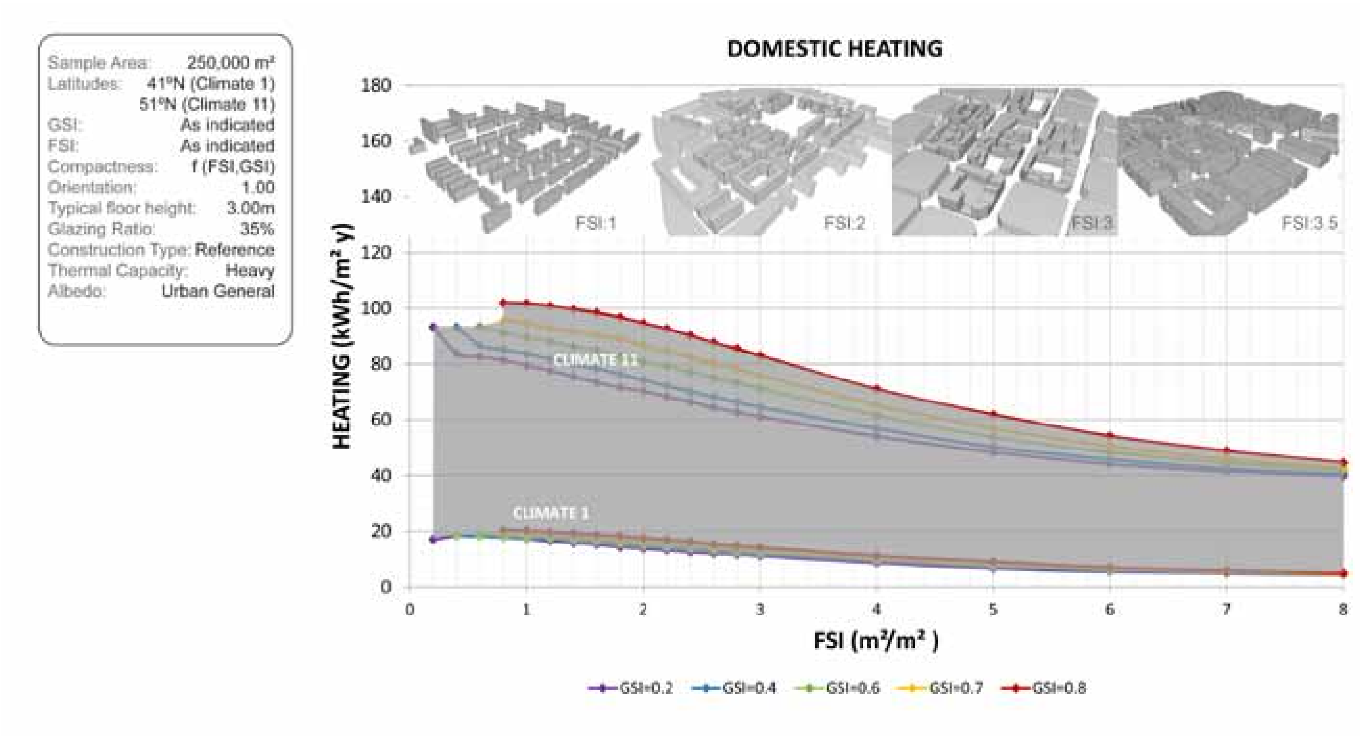


Fig.6-49 Domestic heating and FSI patterns with UEI

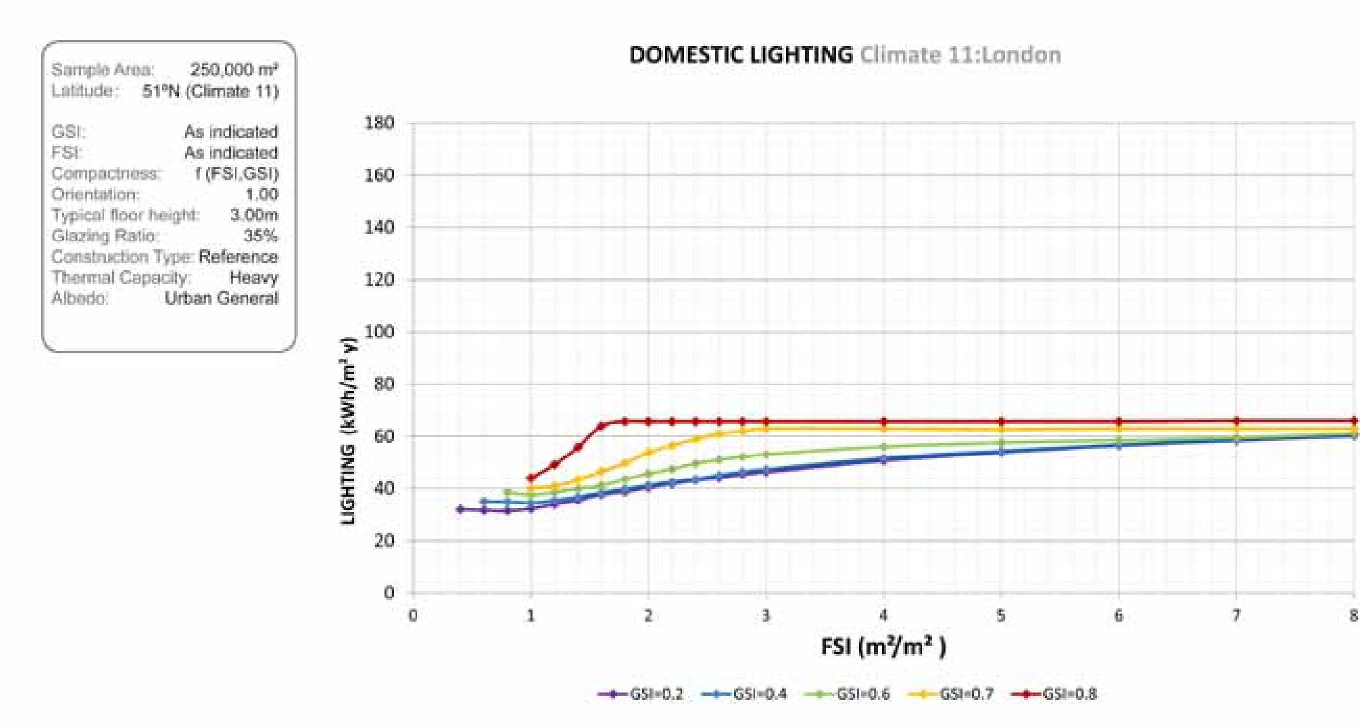


Fig.6-50 Domestic lighting and FSI patterns with UEI

6.7.5.1 Parametric analysis with dependant inputs

Interestingly, when the dependence between variables is introduced in the analysis, the performance patterns change radically. If figures 6-46 and 6-49 are compared, it may appear that one of the graphs is incorrect as they portray trends that are completely diametric. In figure 6-49, when FSI or GSI increases, the Compactness Ratio decreases because it has been made a dependant variable, as in the aforementioned function (eq.2). The heat loss ratio is also modified as a consequence of variations in compactness. Its reduction in dense areas seems to compensate the increase of solar obstruction. Consequently, domestic heating diminishes when FSI increases, contrary to what figure 6-46 had shown. The influence of compactness is more significant than anticipated, to such a great degree that it outweighs the effect of solar obstruction in dense urban areas. This finding could not have been possibly inferred from the evaluation of parameters in isolation. If the question is whether high FSI, on its own, enhances urban efficiency when all other parameters are fixed, then the correct answer would be no, because heating load increases with high FSI (fig.6-46). But if the increase of FSI is associated to an increase in building compactness (therefore a decrease in Compactness Ratio), which has been proven a likely possibility, a potential decrease of the heating load would follow. Only when the variables are connected, the analysis becomes more realistic and it gives a clearer idea of the likely trends in buildings' behavior.

Domestic lighting parametric analysis was undertaken using the same method of establishing a link between compactness and combinations of GSI and FSI. As in the previous analysis, each pair of input parameters had to meet a basic requirement: GSI had to be equal or higher than FSI as otherwise it would contradict the term's definition. In addition, it was noted that lighting estimates were not so reliable when FSI≈GSI, therefore all series started with FSI being slightly above GSI. After these limitations were overcome, the performance of lighting demand against urban parameters was analyzed. It showed a rising trend for denser urban fabrics, both in terms of FSI and GSI. In this case, downsides from solar obstruction and building compactness are combined to produce poorly performing urban structures. When density reaches a certain combination (for instance FSI≈1.5, GSI≈0.8 or FSI≈3, GSI≈0.6) the average dwelling has to rely on artificial light to achieve the reference illuminance targets for most of the occupied hours.

6.8. Generalization and potential applicability

Parametric analysis has identified trends between urban form and energy demand. Although it has been rarely prescribed in planning or measured in morphological studies, the average building compactness was shown as a critical aspect in urban performance. FSI and GSI are familiar terms for planners but they are insufficient indicators and they cannot portray the whole picture. Urban planners need design tools that use planning inputs to provide information to support decision making. The UEI has the potential to include those parameters, analyze them and return meaningful outputs. Three different formats have been devised to increase the flexibility of UEI to specific needs. Each format has a different purpose, and they have been adapted in order to facilitate the workflow and the interpretation of the results.

6.8.1 UEI Spreadsheet

The spreadsheet contains all the algorithms that have been explained in previous sections. It is a simple way to perform quick parametric calculations and to evaluate the potential performance of different scenarios. It allows a great flexibility to describe the designed scenario since up to 12 parameters can be manipulated. The spreadsheet workflow is quite straightforward. The minimum inputs that are required to produce a result are climate, latitude, FSI and GSI. All the other variables can be filled with precise data if they are known or assigned a default value, if they are not. It is expected that default parameters will be commonly used for top down energy analysis of existing urban areas, whereas for design scenarios, the planning team may consider their own set of input values as part of preliminary explorations. As it has been stressed, Compactness Ratio is an important parameter to determine urban energy flows. Therefore, its real value should be ideally inferred, either from measurements or from planning prescriptions (i.e. from the energy strategy of a masterplan that prescribes a compactness range). In case

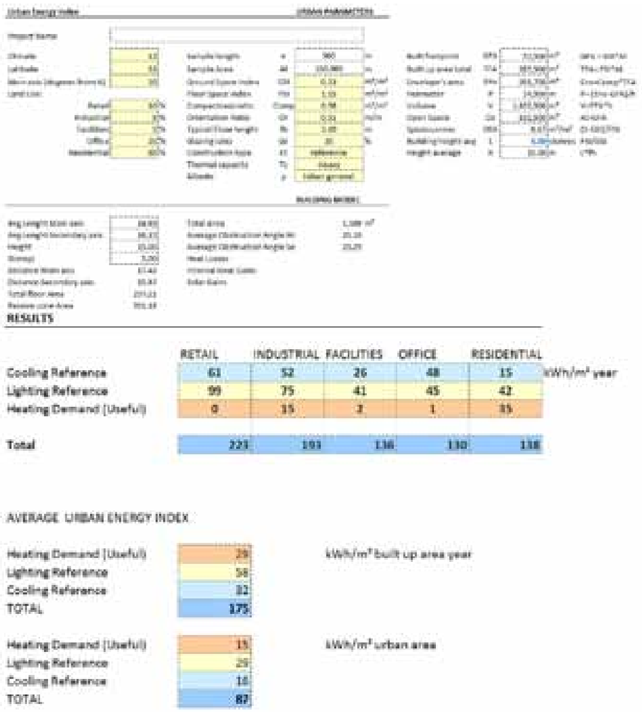


Fig.6-51 UEI spreadsheet interface

the user is not familiar with the term and global compactness cannot be measured, the tool allows for automatic estimation based on the FSI, GSI and the correlation illustrated in figure 6-49. An option "calculate it for me" can be selected and by doing it, compactness is automatically computed as the exponential function [eq.2]. Potential applications of the spreadsheet include:

- **Research**. The tool is designed in a way that it can be easily modified to fit different study purposes. Climate conditions, building elements or occupation patterns can be altered to represent different regions, construction standards and cultural contexts.
- **Practice**. Planning teams and agencies can evaluate the effects of urban standards before they are implemented into local plans. FSI and GSI are commonly prescribed in planning instruments without a clear idea of the implications in building's environmental performance. The UEI spreadsheet allows not only to predict likely trends but also to assess the effect of potential measures such as higher insulation levels or variations in window to wall ratio.

6.8.2 UEI Diagrams

An simpler method to provide energy information resulting from urban form was devised after a series of parametric analysis. It consists on a diagram that only requires FSI and either Compactness or GSI to obtain estimates for the energy load for an specific use, building type and climate (fig. 6-52). The workflow is the typical as in similar charts: the user enters the diagram by selecting the appropriate FSI and moves vertically up to the intersection with the compactness ratio, which is projected horizontally from the left axis. A parallel to the energy reference guides (down sloping thick lines) is traced from the intersection towards the right vertical axis, where the resultant energy value can be read. As in the spreadsheet case, it is possible that the user does not have information about Compactness Ratio. In that case, the energy estimate can be obtained by intersecting FSI with the corresponding GSI curve. The parallel line is now traced from the crossing point between the curve and the vertical projection of FSI towards the right vertical axis. This method is less accurate than using compactness, because it is based on a double correlation: first, compactness is inferred from FSI and GSI, and then the energy estimate is obtained as a function of these two variables, together with compactness. Although uncertainty is higher with this method, trends are consistent with all previous analysis.

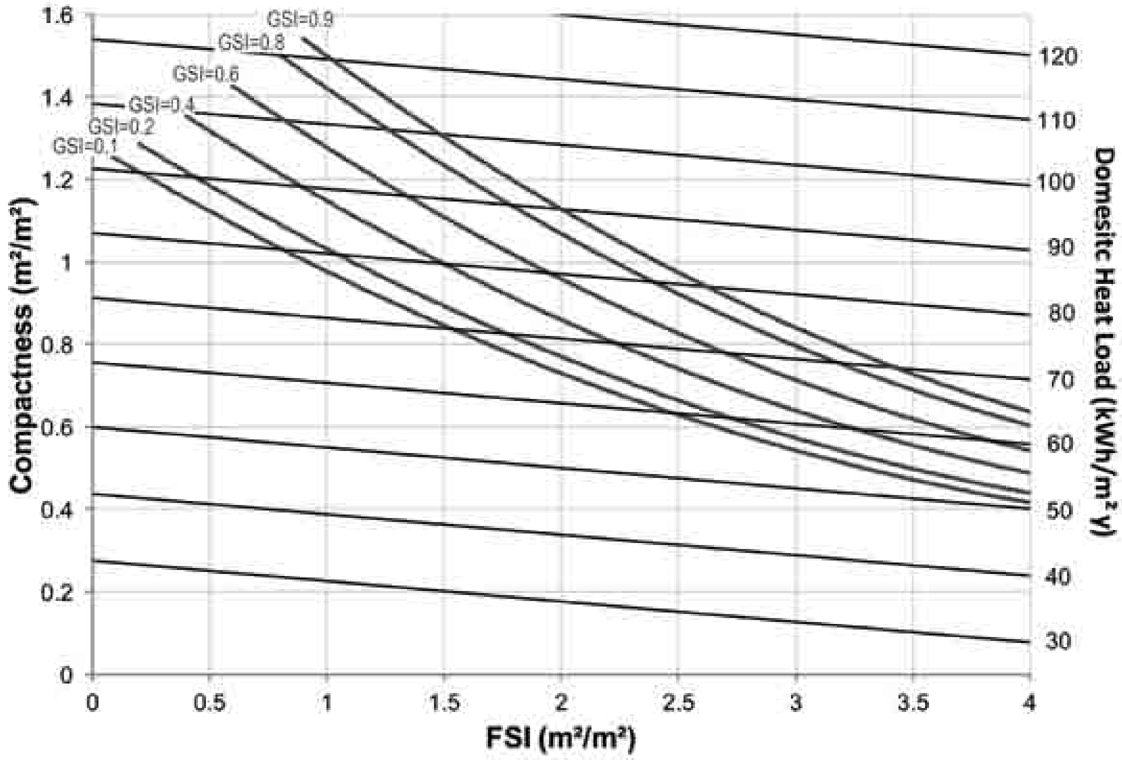


Fig.6-52 "Energymetric" diagram for domestic heating in Climate 11

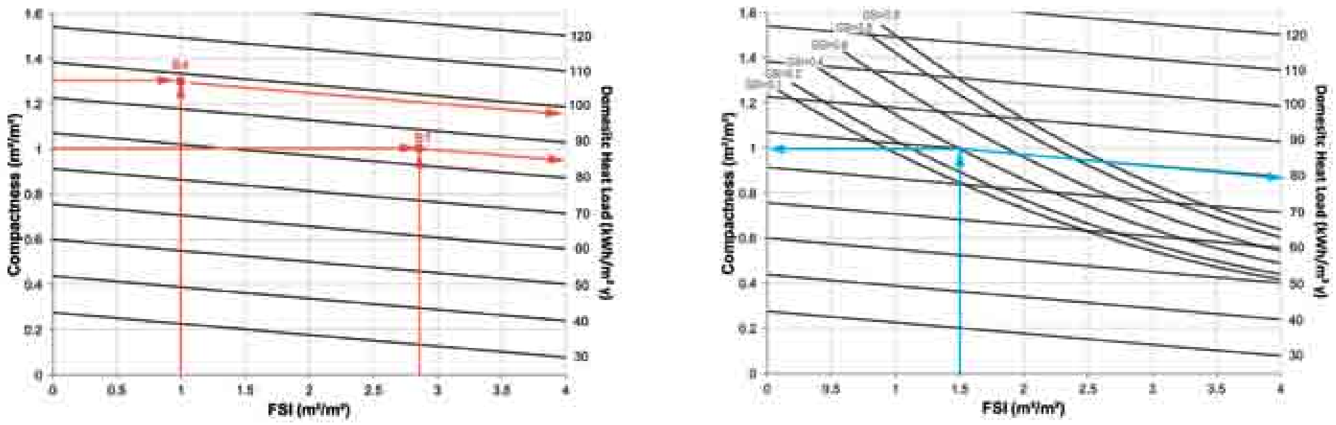


Fig.6-53 “Energymetric” diagram. It can be entered with FSI and Compactness (left) or with FSI and GSI (left)

The diagram has been constructed for specific climatic conditions, building type and energy use. Moreover, default values were assigned to construction, window ratio, occupancy and all other parameters. Consequently, the diagram reflects estimates for those inputs only. This limitation could be partly overcome with the elaboration of further diagrams, covering a strategic range of variations for the most influential factors. This was the approach followed by LT Method, which provided climate specific diagrams for different building types, lighting levels and internal gains[79]. Potential applications of this method could include:

- **Research**. The diagrams facilitate the discovery of trends as they show continuous correlations that can be visually analyzed. They illustrate energy variations along the different axis of the diagram. For instance, given an FSI, the effect of different GSI can be noticed by simply exploring how the vertical projection intersects with the GSI curves. In the case of fig. 6-52, it can be inferred that the increase in GSI penalizes domestic heating consumption. For an FSI=2m²/m², variations in GSI can induce a potential increase of up to 30%. The effect of compactness can be likewise read from the diagrams. For the same FSI, every 0.2 Compactness Ratio increment raises domestic heating around 12kWh/m². Similar deductions can be done if compactness or GSI are fixed and the trend of the other two remaining variables is analyzed. Overall, these diagrams have to be taken as propositions that may spur research on urban energy. They represent a legible starting point to be challenged and improved, either to make it more precise or to challenge the trends that it highlights.
- **Practice**. If the diagrams are fine-tuned for different location and building types it may become a useful supporting tool, especially at the early stages. It can be used to establish reference values and targets. The diagram can be calibrated with current construction reference values and hence the potential range of energy performance of the new buildings in the area can be predicted. It can be also employed as a communication instrument as it provides a graphic visualization of energy patterns in a very synthetic way.

79 Baker & Steemers, 1992

6.8.2.1.UEI Diagrams. Creation and calibration process

UEI diagrams can be plotted for every climate and building type included in the UEI spreadsheet. The elaboration of the diagrams requires of several steps. The example illustrated here corresponds to domestic heating for climate 11. It was generated as follows:

- Compactness lines. In order to obtain domestic heating as a continuous function of FSI and Compactness, a multiple linear regression analysis was carried out. 165 different combinations of FSI and Compactness Ratio were calculated in the UEI spreadsheet to create the samples for the regression. The following statistics summarize the output from the regression:

Regression formula:

Heat Load = 11.9811+3.1430*FSI+63.5953*Comp [eq.3]

Table 6-3 Regression Statistics

Regression Statistics	
Multiple correlation coefficient	0.99278147
R-Square	0.98561505
Adj R-Square	0.98543746
Standard Error	5.43625971
Number of observations	165

The formula was used to find the corresponding compactness values in energy isometric lines. Energy isolines were to be divided in regular intervals of 10kWh/

m². To define these lines, two FSI values were obtained for each energy interval. The formula **[eq.3]** was used to find the Compactness Ration that corresponded with each combination of FSI and Domestic Energy. In this way, the line was defined by the two pairs of coordinates (x,y), where FSI was the value for the horizontal axis and compactness was the value for the vertical axis. The same procedure was repeated for every other interval. The following graphic illustrates this methodology (fig.6-54):

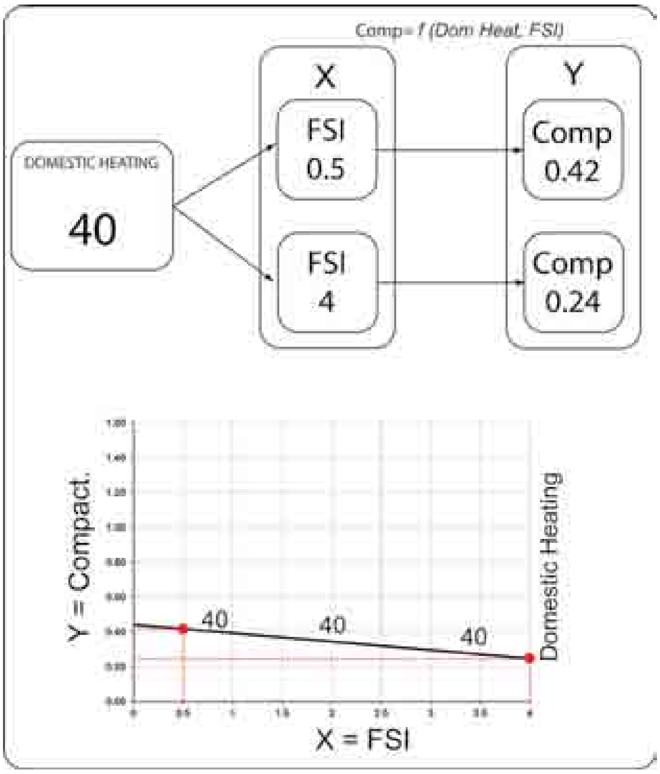


Fig.6-54 Energy isometric lines generation procedure

- GSI curves. The elaboration of GSI curves had to be done in a different way. The regression analysis that took FSI and GSI as independent variables and domestic heating as the dependent one was not conclusive. The standard error was too high (around 40) and the correlation weak (r^2=0.23). After performing multiple regressions analysis, it was found that GSI has, in fact, little statistical significance in the magnitude of Domestic Heating Energy, as Compactness and FSI explained most of the variations in the observations. However, since the process to calculate compactness can be a complicated task or it can be simply unknown at the time of the analysis, the interest of including GSI remained as to facilitate preliminary assessments, even though it was assumed that it would be less accurate.

An alternative was devised, which consisted on relating GSI with compactness instead of domestic heat load. Once compactness was known, and given that FSI is an input by the user, the energy estimate can be obtained directly. A logarithmic regression analysis provided the best match to correlate Compactness Ratio with FSI and GSI. The resulting correlation is an exponential function, which has been already used in previous sections [**eq.2**] :

Comp: $1.2289 * 0.7507^{FSI} * 1.7235^{GSI}$ [eq.2]

Table 4 Regression Statistics

Regression Statistics	
R-Square	0.45
Standard Error	0.22
Number of observations	28

Although the coefficient of determination is not very strong (r^2=0.45), the strategy of linking GSI and FSI with compactness has two further advantages:

- Firstly, it emphasizes the fact that there is a certain connection between GSI, FSI and the resultant compactness. Even though this is not deterministic and it depends on other factors, the combination of FSI and GSI defines a Compactness Ratio that is statistically probable. More importantly, it establishes that certain values of compactness are unlikely to occur in combination with specific FSI and GSI.
- Secondly, the workflow of the diagram is simplified by connecting GSI with Compactness Ratio. Both Compactness Ratio and Energy demand can be found at the vertical intersection of FSI with the GSI curves, the former by going horizontally leftwards and the latter by following the down sloping line to the right vertical axis. This is because GSI curves were associated with compactness instead of heating demand. Once compactness is known, its stronger predictive potential is used to estimate heating.

As in the previous case, the function obtained from the regression (eq.2) is used to plot the curves which are to define equal values for GSI. In this case, it is necessary to define the intervals and more input values for FSI to find the corresponding Compactness Ratio. As these are not lines but curves, the function needs to be solved several times to obtain enough references to delineate it.

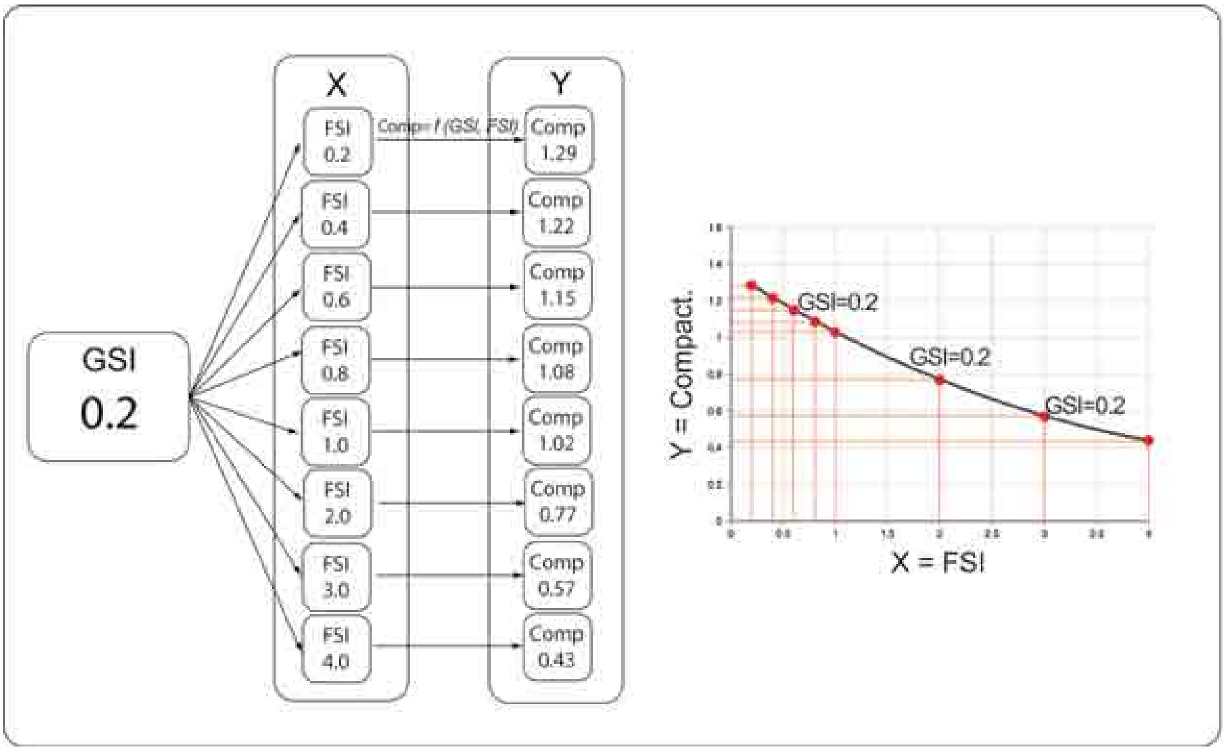


Fig.6-55 GSI isometric curves generation procedure

6.8.2.2.UEI Diagrams. Validation and reliability

The twenty eight samples were used to test the accuracy of the diagrams. The use of real cases was the only way by which the accuracy of the diagram could be tested because compactness could not be compared otherwise. The results from the samples were plotted in two ways, first by entering the actual values for FSI and Compactness Ratio and then by introducing FSI and GSI (i.e. pretending that compactness is unknown). The mere plot of the samples (fig.6-56) in the UEI diagram provides some interesting insights already.

An unexpected insight is observed regarding the relative compactness for every density range in the five different cities: Northern cities consistently present more compact buildings, for a similar FSI range, than southern cities. This will be also reflected on how compactness prediction performs. In the diagram showed in figure 6-56, the smaller the vertical distance between outlined and solid dots, the more accurate the predicted compactness was. Or, in other words, the closer the real compactness is to the values that could be expected for that FSI and GSI. If the outlined dot is above the solid dot, it means that the sample is more compact than expected and, conversely, if the outlined dot is below the solid dot, the sample is more exposed than expected. Interestingly, compactness was predicted differently across cities, sometimes it was overestimated and sometimes it was underestimated, but there was a strong consistency within each city. Moreover, this consistency seems to extend to cities within similar climatic conditions. The urban samples from Southern climates, those from Madrid and Barcelona, are clearly more exposed than predicted whereas the examples from Berlin and London are all more compact than expected. Compactness was underestimated in colder regions. The intermediate climate, Paris, is closer to predictions and can be slightly above or below the expected values. This observation suggests that existing urban fabrics have been adapted to local climate. It has been repeatedly mentioned how reduced exposure of the building's envelope diminishes heat losses. The adoption of compact solutions in Berlin and openness in Barcelona can be a regional adaptation to different local climates. If this has been determined by conscious decisions, by chance or it is a result from traditional customs are interesting hypothesis that deserve separate research. A classic morphological analysis may not have unveiled these subtle differences between similar typologies in different cities and it may have categorized urban form regardless of this characteristic that results so critical for buildings performance.

Looking now across cities, better predictive potential is found for FSI values between 0.6 and 1.5 m^2/m^2, while the discrepancy between predicted and observed compactness increases beyond 2 m^2/m^2. These patterns are however noticeably less consistent than those identified within cities, which suggests that the correlation between compactness, FSI and GSI would be stronger if it were city-specific.

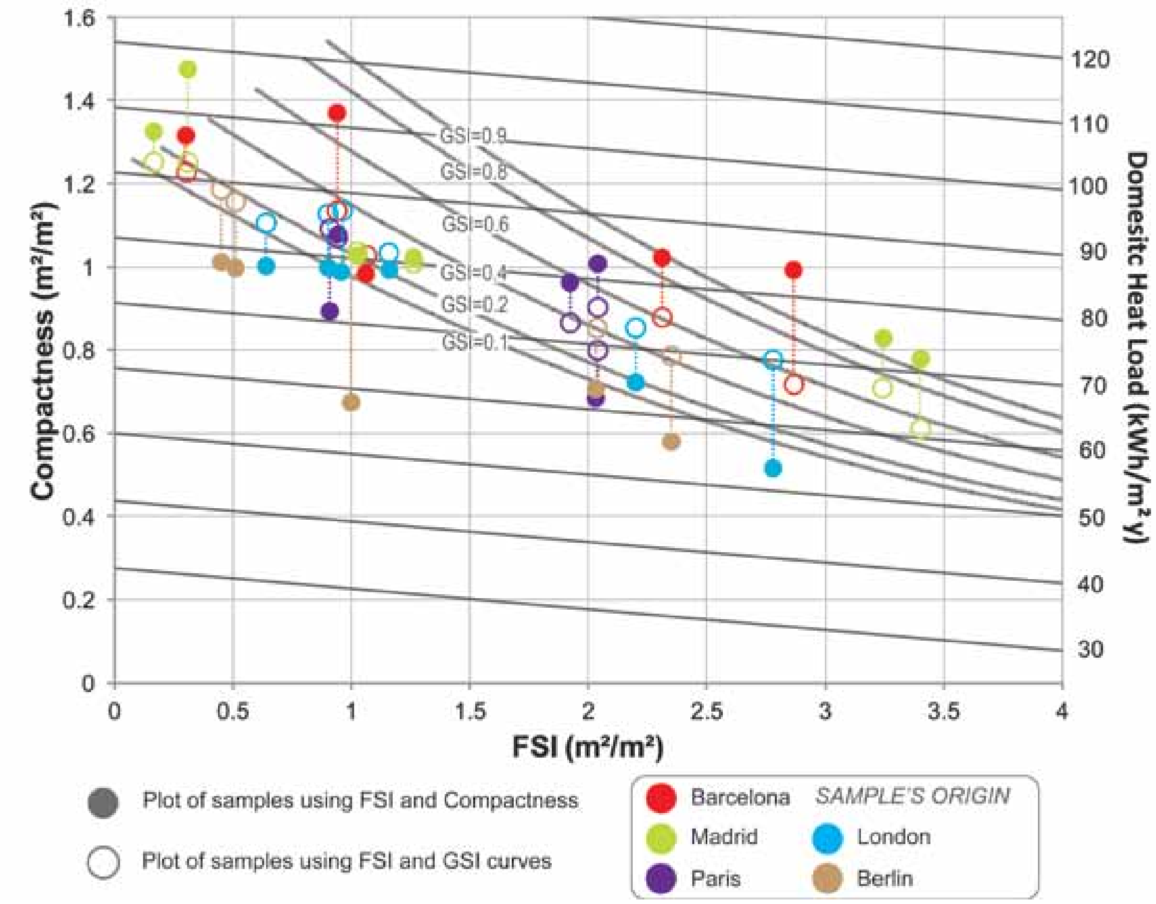


Fig.6-56 The 28 eight samples, this time plotted in the UEI diagram showing the difference between knowing the exact compactness and deriving it from GSI curves

Table 5 Correlation Statistics

	FSI&Comp	*FSI&GSI*
R-Square	0.94	0.71
Standard Error	3.06	9.3
Number of observations	28	28

The scatter plot shown in figure 6-57 illustrates the correspondence between the UEI spreadsheet and diagram estimates. It confirms that the reliability of the diagram differs greatly depending on how it is entered. As expected, entering with FSI and Compactness Ratio is the best option, as it ensures a closer correlation with estimates calculated in the UEI spreadsheet. If this is not feasible and the compactness has to be inferred from the intersection with GSI curves, the predictive potential falls significantly. It can be also observed how overestimation of compactness has ended up in underestimation of the heating load. As illustrated by figure 6-56, Madrid and Barcelona presented higher levels of exposure (therefore higher Compactness Ratio) than predicted. It means than better performing buildings were assumed and, as consequence, the heat load returned by the diagram is lower than it should be. Conversely, London and Berlin's actual fabric was reported as being more compact, in relation with the FSI and GSI, than the average trend. For the same reason, the predictions returned by the diagram for these two cities are slightly overestimated. It is important to remark that the diagram has not returned any contradictory value within the same city. In the sense that, when a value has been predicted higher than other in the UEI spreadsheet, it is still higher in the UEI diagram.

Knowing that the UEI diagram presents consistent patterns for each climate suggests that a better estimation would be achieved if the relation between FSI, GSI and compactness was calibrated for every different region. Since the charts are already climate specific, it would not add further complexity to the final workflow. The calibration would imply the selection and processing of a good number of urban samples from that climate to infer a correlation that was specific to it and, therefore, stronger. As the aim of this study is to develop and explore the analytical technique

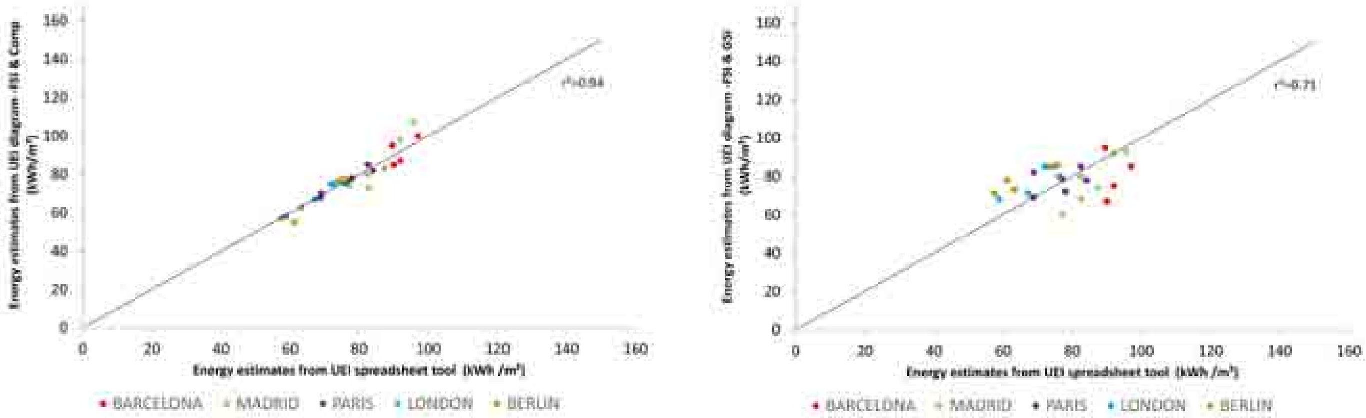


Fig.6-57 Scatter plot of predicted heating demand using the UEI diagram versus the UEI spreadsheet. Left: FSI and Compactness are known and energy is estimated using the isometric lines. Right: FSI and GSI are known while compactness is derived by using GSI curves

rather than its fine-tuning, such task will be deferred for further research. The key task for the correct calibration is therefore to find a sound correlation to predict compactness. At this point, it must be stressed that such calibration would only involve the GSI curves as it has been demonstrated that the UEI diagram is accurate when it is entered with a known FSI and Compactness Ratio.

6.8.3 GIS-integrated UEI

Geographic Information Systems (GIS) have become the most generalized and widely used family of tools in urban research and practice. Their ability to combine geographic data with multiple layers of information, as well as their capacity to perform complex calculations have provided enormous possibilities for spatial analysis, visualization and representation. The integration of UEI in GIS aims to extend the capacity of the tool to handle big datasets and, eventually, to perform energy assessments of larger urban areas, from neighborhood scale up to the whole city.

Several options were considered, discussed and tested. The first alternative was to write a code in a computer programming language (java or python as preferred options), which could be compiled and executed as part of a GIS platform or even as a stand-alone application. The main advantages from this solution were accuracy and flexibility. All the algorithms and calculation procedures used in the original UEI spreadsheet could be embedded into the code and hence the integrity of the tool would be preserved. Interface and menus could be customized to facilitate the introduction of data and the selection of parameters. The resulting tool could be more user-friendly and appealing to designers as it would integrate advanced visualization techniques and other supporting graphical outputs. Despite this potential, the amount and nature of the work that the development of the code involved have discouraged its inclusion as part of this thesis. Hundreds of hours would be spent in mechanical computing work and less would be available for urban analysis. Moreover, the objective of integrating UEI can be attained by simpler alternative paths. Therefore, the decision to postpone this option for future research was taken, possibly as part of a broader project within a multidisciplinary team.

The alternative, simpler, option consisted on the use of an application that is a commonly included in many GIS packages to create models. Models are, in this case, understood as “workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input”[80]. It is a kind of graphic interface to produce codes for GIS as the models created with this application can be actually translated as a script into Python[81]. GIS platforms that currently allow model-building include ArcGIS, Grass GIS, Sextante (as plug-in of GvSIG), and Quantum GIS (undergoing) among others. All these tools are freely available, with the exception of ArcGIS, which is run by the commercial company ESRI. This is not a minor detail, free software can reach to a larger community of potential users and researchers, which means that any application developed within them can be exploited and evolved by almost anyone with interest in the field. That enhances innovation and the creation of new knowledge. The main handicap with free software is that, in some cases, or for certain applications, it may fall behind, in terms of capacity, operability or stability. In contrast, commercial software needs to be constantly updated to improve their products and keep a competitive advantage. After testing GvSIG-Sextante and ArcGIS modelers, the latter was selected mainly due to the greater stability of ArcGIS when handling large maps and databases.

80 ESRI (2012) ArcGIS 10.1 Help “What is ModelBuilder?” Esri Inc.
81 A programming language

6.8.3.1.GIS Model Development

The following objectives were established at the start of the UEI GIS model development:

- The primary aim of the model was to generate an application that could estimate the potential energy demand derived from urban morphology.
- This version may be considered as a preliminary test to evaluate the potential of such application in practice and research.
- The basis and scope of the tool were the same as for the original spreadsheet, an instrument for comparative analysis to inform urban design and governance.
- The integration in a GIS platform aimed to take full advantage from the analytic and visualization capacity of these tools.
- Its use should not require advanced expertise on buildings energy although that would be rather useful to interpret the results correctly.
- The model should be flexible so as to respond to a wide range of possible uses, allowing its adaptation to different climates, locations, building types and scales

The workflow would consist on the identification of an study area, for which a proper cartography should be obtained as a prior requirement. Cartography should include, at least, information of the buildings' height and footprint. The rest of the process would be automatized and the output would be obtained as a heat density map, a grid or as statistical values. Future development may include options to introduce specific parameters for construction or building types, but at the moment they will be assigned default values. The quality of the cartographic base will determine, to a great degree, the accuracy of energy analysis. It can be expected that, in a near future, detailed databases with information on every building in the city, including age, construction or number of occupants, will be available. Right now, many of these values have to assumed or surveyed, which is impractical for large study areas.

As mentioned before, the model was elaborated in ESRI®ModelBuilder™, the graphic modeler of ArcGIS. The model includes a sequence of codes that translate the calculation process that was devised for the UEI spreadsheet into readable GIS commands. When building the model, a decision had to be taken, either to emulate the structure of the original UEI model, which would increase complexity and computing time, or to get a simpler version using some shortcuts. Since this theses is understood a primer step into a complex research, it was felt that there was no need to undertake cumbersome tasks when simpler but rigorous options were available. Therefore, a simplified model was initially built with the intention of testing it and exploring its potential applications.

The model elaboration process can be summarized in five main calculation steps:

Step 1- Setting the reference grid

The first step to perform an energy assessment using UEI model is to set a shapefile layer[82] that contains the study area's building footprint and a field with the building height in the attributes table. Then, the UEI model will create a grid, using the tool "fishnet", as to have a controlled area division that can be used as reference for the calculations. The dimensions of the cells that compose the grid will determine the resolution of the final maps. The model has established a 500x500 m default cell to maintain the same dimensions as the real samples and because it balances adequate resolution and acceptable computing time in most cases.

Once the grid has been set, it will be intersected with the study area's building layer. By this process, every building will be assigned an ID that indicates the cell they fall in. If a building falls into two or more cells it will be divided in as many parts as cells it falls into and IDs will be assigned accordingly. As a preventive measure, a command to remove all elements with height below 3 meters was set. It prevents estrange objects, such as urban furniture from being interpreted as buildings.

Step 2- Calculation of FSI and GSI

Although it has been demonstrated that compactness is a critical parameter, its calculation can significantly complicate the model and, more importantly, computing time when handling big areas. A similar remark can be made about orientation. None of these two parameters are considered in the simple version of the model, which can be considered as a mapped equivalent of the UEI diagram. The later calibration and validation process may inform about the need to reconsider this decision. Two parameters are calculated by the model at this step: FSI and GSI. The rest of calculations will follow from these two values based on pre-established correlations.

To calculate GSI and FSI, several subroutines are undertaken in the background. First, the area of all buildings' ground floor is found and stored in a field named "GFA" (Ground Floor Area). This can be directly done with the tool "Calculate areas". Then, a new field is created in the attribute table named as "TFA" (Total Floor Area). This field will be populated with the results from the operation "GFA x h", where "h" stands for the building height, in number of floors. Buildings which are adjacent and have the same height are dissolved to reduce the number of different objects and simplify the model. Now the TFA and GFA are divided by the cell area to obtain FSI and GSI respectively, the results will feed two newly created fields in the attributes table.

82 A shapefile is a GIS layer in vector format

Step 3- Calculation of Compactness Ratio

As mentioned before, if compactness were to be calculated as in the original urban samples, the time to complete the operation would take much longer that all other processes in the model. A shortcut has been devised, at least for the preliminary version. The exponential correlation between FSI, GSI and compactness that was signaled in equation 2 will be reclaimed to infer values in a similar way than in the UEI diagram. Therefore, a new field will be created in the attributes table to accommodate the results from this formula [eq. 2] :

$$\textbf{Comp: } 1.2289 * 0.7507^{FSI} * 1.7235^{GSI}$$

This algorithm was found accurate for Paris, but it overestimated Compactness Ratio in Northern locations while it underestimated it for Southern cities. This is not considered a decisive limitation as results will still be meaningful for comparative intra-urban analysis.

Step 4- Calculation of Energy Demand

The formulas obtained from regression analysis, which have been calibrated for each location, are used to perform the energy calculation. The following expressions are used for domestic heating in London and Barcelona:

LONDON:

Heat Load = 9.29+3.13*FSI+5.03*GSI+63.57*COMP [eq.5]

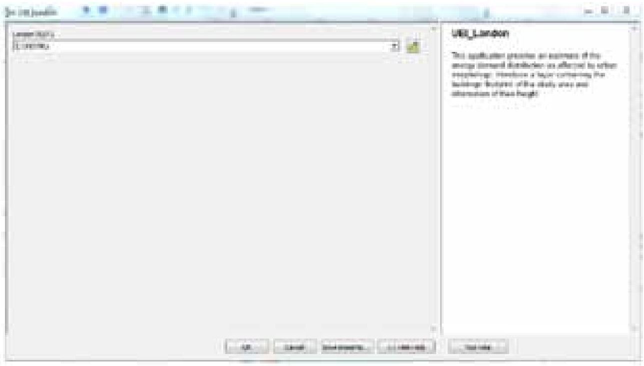
BARCELONA:

Heat Load = -1.10+0.73*FSI-2.05*GSI+16.90* COMP [eq.6]

The results from this expression represent the average estimated demand for all the buildings that fall in each cell. The values are stored in the corresponding field of the attributes table.

Step 5- Representation and visualization

Several options were considered for representation. One alternative could be to visualize the analysis grid with a color scale, showing the heat load in each cell. However this was too abstract and rigid and it did not capture well the transitions between urban zones. The preferred solution consisted on the creation of a new layer of points, located at the centre of each cell to then interpolate the values across the grid. The final outcome is a density map, in which the dimension is the heating load.



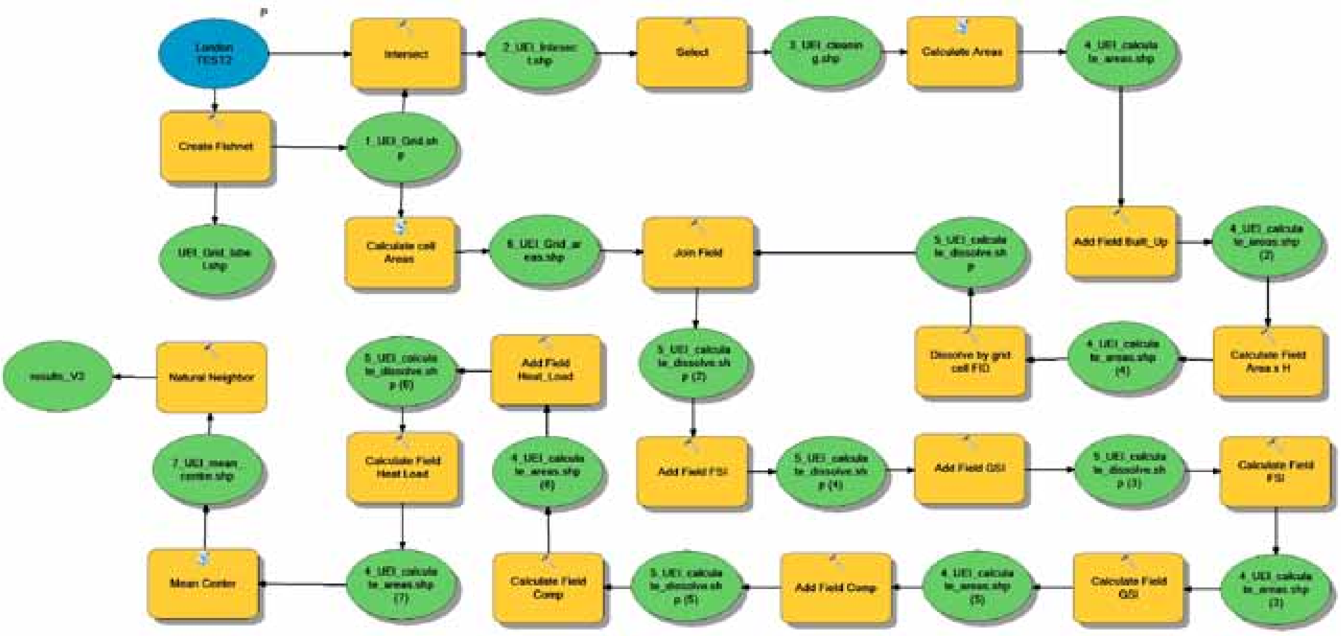


Fig.6-58 Starting menu (top) and ModelBuilder diagram (bottom) to integrate UEI calculations in GIS

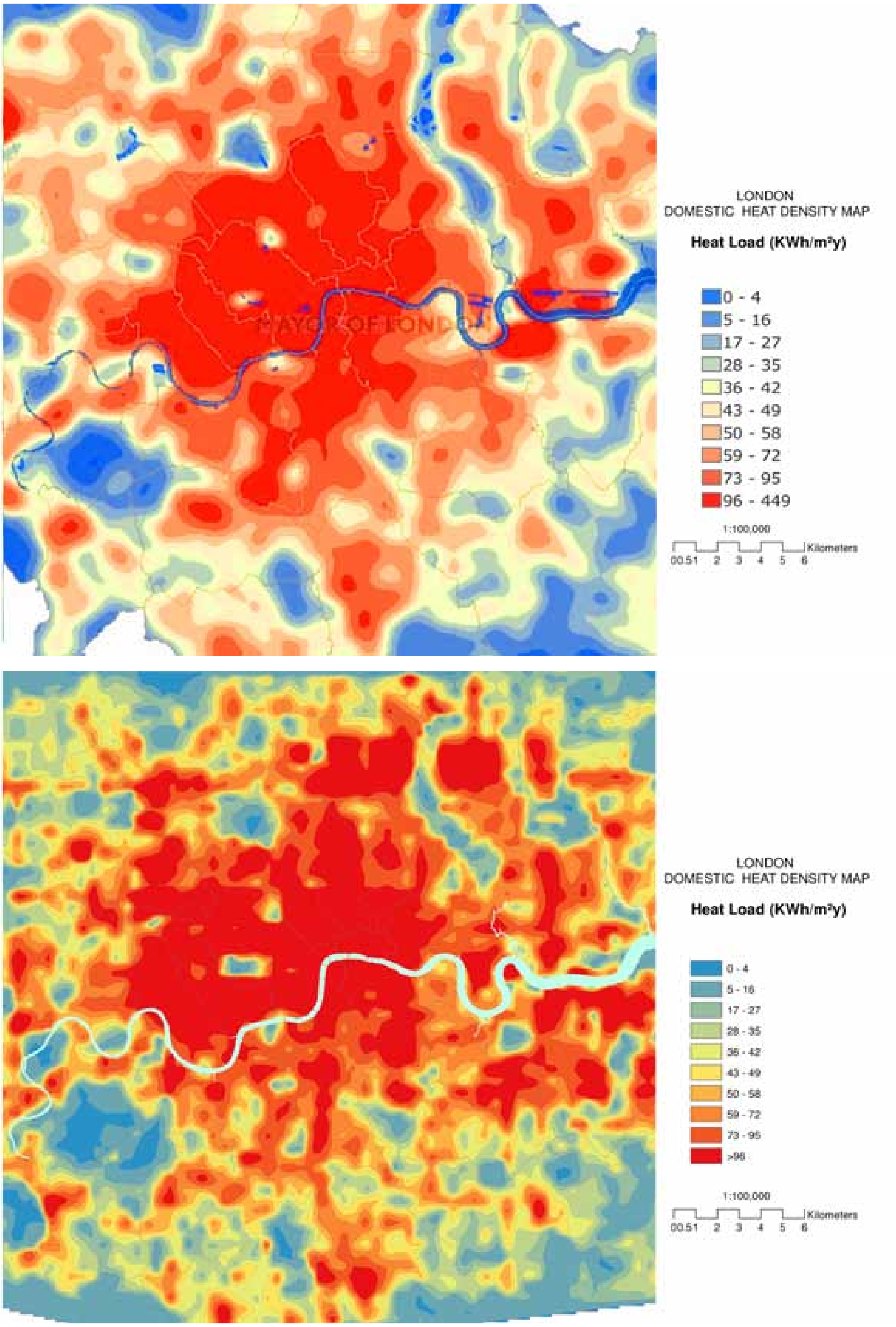


Fig.6-59 Mayor of London's heat map (top, source: londonheatmap.org.uk) versus UEI domestic heat map (bottom) for London. The similarity in scale and distribution is a promising outcome

6.8.3.2. GIS. Validation, visualization and applicability

The validation of city-wide energy analysis is limited by the scarce reliable references for comparison. If, in addition, the analysis deals with the spatial distribution of energy loads across the entire city, the references become almost null. This UEI GIS application intended to cover that gap. Therefore it was not expected to find available equivalent software that could be used to compare the outputs[83].The best available reference was a project, funded by the Mayor of London, to elaborate heat maps in the boroughs of Greater London[84]. Its aim was to identify potential sites for energy decentralization, so that data regarding fuel consumption, major consumers and heat density was compiled. The heating density maps elaborated for that project used a combination of measured and estimated data for buildings around the city and they have been illustrated in kWh/m² of land (not heated area or built up area but the total area, including open spaces). The final outcome has been plotted at a low resolution for the entire city. Online navigation allows for more zooming and increased quality but the render layers cannot be downloaded. Geospatial information is available for each London borough. However, they consist on raw data and the procedure they followed to produced the map is neither described nor it can be inferred from the type of information contained in the layers. Consequently, the best possible option was to undertake a simple visual comparison between a map plotted from UEI data and the Mayor of London's Heat Map. As illustrated by figure 6-59, the UEI map stands the comparison well. Despite the fact that both maps have been produced from quite opposite techniques and different sources, they present a similar spatial distribution and, more importantly, a similar range of magnitudes, which is quite remarkable. The heat load distribution, mapped in this format of kWh/m² per land area, is determined, to a great extent, by building density. The denser an area is, the more heating will be demanded. This is a mistake that geographer would call "population dependency" as the variable under scrutiny (energy demand) will vary depending entirely on the dimension of another variable (typically population, in this case built up area). It will be therefore necessary to normalize the results to make energy demand independent from building density and thus provide information about the energy efficiency of the urban fabric.

Heat density maps referring to the amount of heat load per urban area do not differ much from building density maps. But there are other aspects that heat maps may unveil. One of these aspects refers to the areas of the urban fabric which are more likely to require lower energy to meet comfort standards inside buildings. The UEI GIS application evaluates the urban key parameters that determine that demand. In this case, the resulting map has taken the average kilowatts per hour that are used per unit of heated floor area. This gives a measure of urban efficiency which is not so directly related to density but to the performance of urban form (fig.6-60)

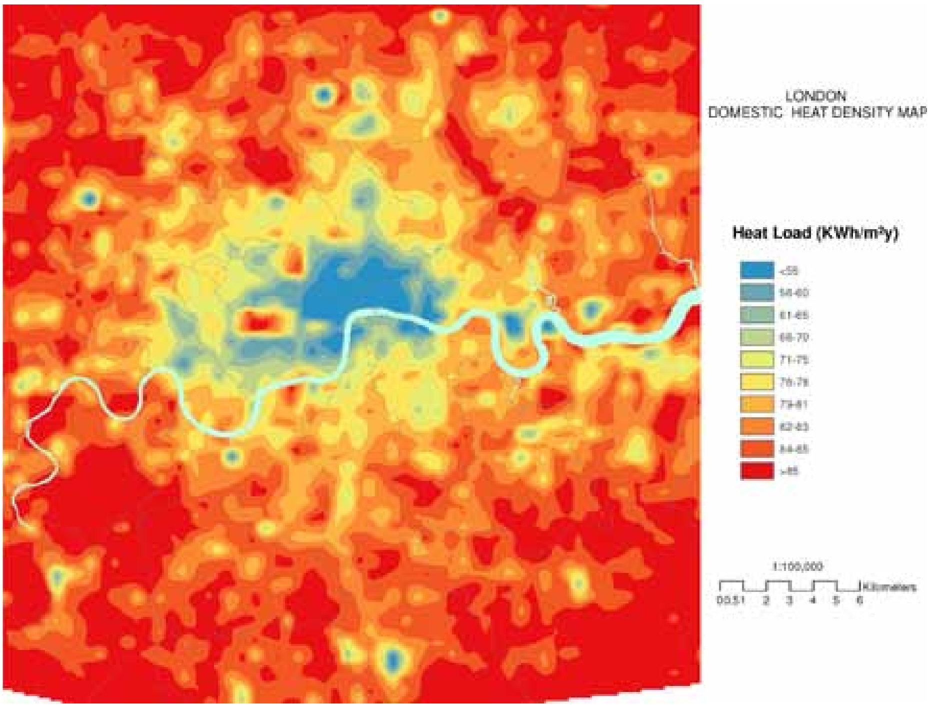


Fig.6-60 London heat map per heated area using UEI

83 There are some software tools that claim these capability (UrbanSim) but any of them was accessible when this research was carried out

84 londonheatmap.org.uk [last accessed 23rd January 2013]

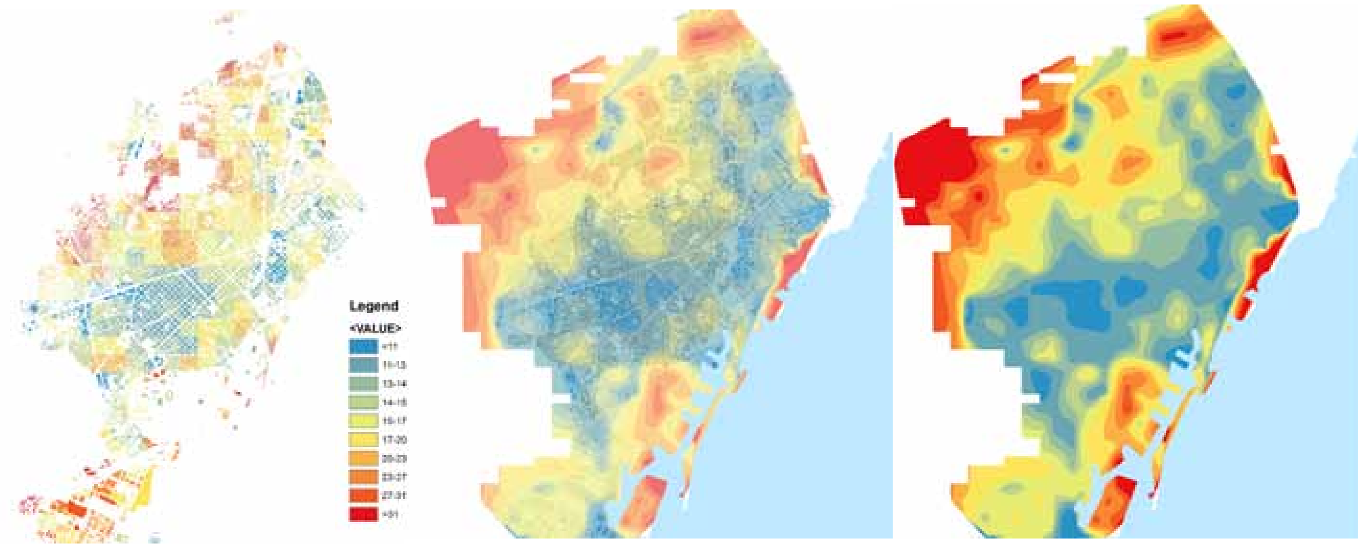


Fig.6-61 Domestic heat maps for Barcelona. Left: Colored buildings. Centre: Overlaid information Right: Only heating

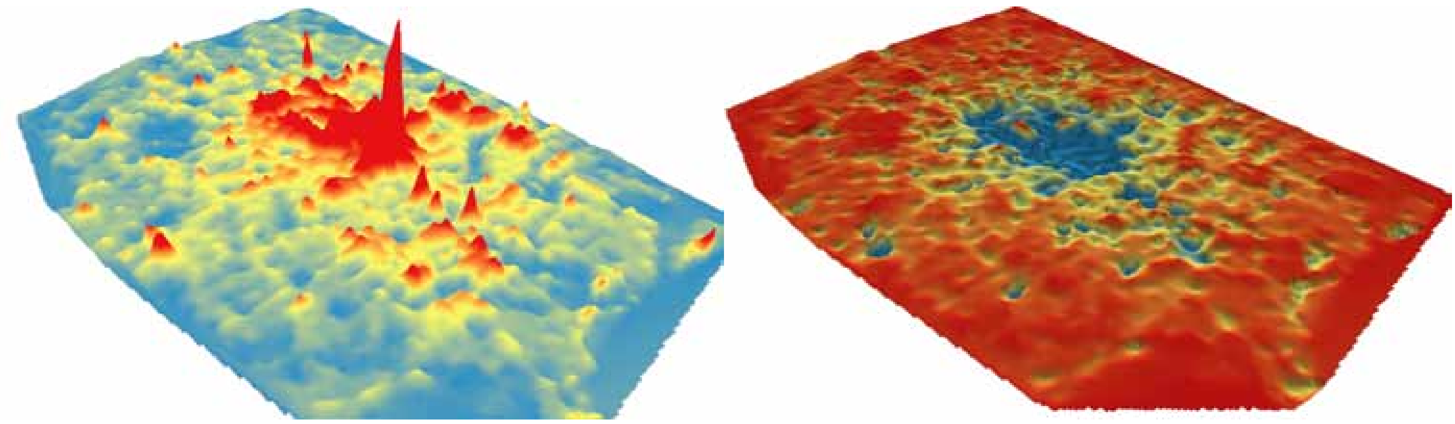


Fig.6-62 Three dimensional representations of domestic heat density for London: per unit of ground area (left) and per unit of heated space area (right)

This way to express the potential energy demand may be also seen as a little ambiguous. Rural zones appear to consume more heating energy than buildings in central locations, which is actually in agreement with empirical observations. However, it may be counterintuitive to consider that, for instance, the urban structure of the City or Canary Wharf are more energy efficient than a little parish in Richmond. It may be necessary to emphasize that what is being assessed by this map is the potential of buildings to capture and retain heat according to the existing urban morphology. Electricity, cooling or behavioral patterns are not being considered. Different modes of visualization were explored to express data in clearer ways. In a first experiment (fig. 6-61), buildings were colored after the heating scale, each block was assigned the color that corresponds to the average domestic heat demand of its cell (in the analysis grid). This map has the ability to combine the visualization of heating and building density. Urban typologies can be identified and zones without construction are left blank, which facilitates the visualization of the city. Nevertheless, using buildings to represent energy demand may lead to a different kind to delusive interpretation, related to ecological fallacy. The idea that individual buildings perform in the same way as the group or area they belong to. This interpretation would be misleading since the energy estimates were mean values, calculated from groups of buildings whose performance may differ greatly from on to another. A second variant was to overlay heat density and buildings layer while applying a degree of transparency so that the information from both layers can be identified. It overcomes the issue with ecological fallacy while retaining the ability to associate relative performance to urban morphology. Those neighborhoods that perform poorly can then be identified and the morphological reason for their bad behavior could be also visually traced in the map.

Three dimensional formats were explored to portray the spatial distribution of energy intensity (fig.6-62). It was found that density maps per ground area had a greater potential for communication than their equivalents two dimensions. The tabulated color scale did not allow the visualization of the full spectrum of variations at peak areas. For each interval, there was a false sense of homogeneity that does not relate to what has been unveiled by the 3D map. If the application is calibrated for different energy uses and building types it would be possible to draw comparative analysis about the distribution and dimension of domestic and non domestic energy demand as related to urban morphology. In contrast, if the energy demand is represented per unit of heated area, the 3D map results less clear. The central city, which tends to be more compact, seems to sink while the rural zones acquire the appearance of a flat plateau. Although the map is appealing and it reminds bathymetric charts[85], it can hardly transmit the idea that the sunken zones are areas with a better relative performance. The potential applications of the UEI GIS application are broad and diverse. They mainly relate to the analysis and visualization of existing cities although it could well adapt to new developments of a certain scale:

- It is a visualization tool that helps to communicate data and patterns in a comprehensible way. The three diagrams provide an intuitive message that can be used to get messages across a general public. The perception of urban areas is typically determined by mental associations that refer to issues such as safety, beauty, home prices or their relative position in the city. In an age of rising energy prices, information on how urban form may affect energy expenditure will be valuable and worth considering when moving home, for instance.
- It is a supporting tool to inform plans and policies at local level. Regarding urban governance, it identifies the areas of the city where, according to the urban form, buildings are more likely to require a higher energy demand to meet heating needs. That information, in combination with other criteria, such as household income, could be used to define priority areas for renovation policies and building upgrade subsidies.
- It is expected that actual energy measurements will be collected at building level in the medium term. In that moment, predicted demand could be compared against real demand, which, on the one hand would allow a better calibration of the model and, on the other hand, it would identify discrepancies. Buildings whose consumption goes far beyond reference values could be penalized to encourage energy saving measures.
- A similar approach could be applied in the planning application process. Currently, building applications must include simulations to compare the expected performance of the proposed project against a reference building. For large infill developments, the comparison between different urban structures could be drawn using the UEI application.

6.9 **Discussion**

In this section, it has explained the development and validation of a tool to take account of urban morphological parameters, such as urban intensity (GSI and FSI), compactness (Comp) and Orientation Ratio, together with location and climate, to estimate energy demand. Additionally, the tool calculates the effect from variations in the typical floor height, glazing ratio, insulation, thermal capacity and albedo at urban scale. The calculation procedure takes these inputs to derive a notional grid that retains the critical characteristics of the original urban fabric. Then it applies a 14-steps routine to obtain loads for heating, cooling and lighting. The whole process has been automatised using an spreadsheet, so that calculations are instantly performed. Optionally, the land use break down can be introduced. The model incorporates different specifications and default values for different building types and it provides output results accordingly. Results are given as useful load per square meter of construction (built up area) for each building type or as primary energy per land area. The latter gives an idea about the average intensity of energy demand in relation with buildings, while the former is closer to the notion of energy density. The integration of this application in a GIS platform also allows the automatic creation of city-wide energy density maps. Unlike existing energy models, the UEI tool starts from urban parameters, which allows quick estimations for large scale urban areas, even city-wide in a top down approach. The tool can be used in three different formats:

- **Spreadsheet**, which provides the most accurate results while allowing a great flexibility.
- **Regional diagrams**, by which energy can be calculated by simply intersecting values of FSI and GSI or Compactness in the graph
- **GIS integrated model**, which was created to extend the capabilities of the tool, improve the visualization and facilitate the automatic measurement of input parameters.

85 See, for instance, www.gebco.net/about_us/overview/

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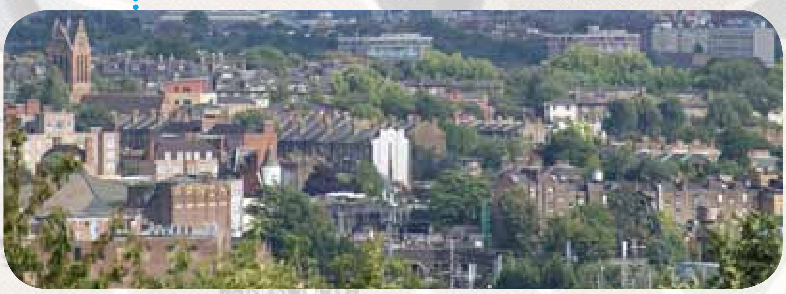
THE CITY AND THE BARBICAN



KENTISH TOWN

CANARY WHARF

SAINT PAUL AND THE SHARD

CHAPTER 7

LONDON. THE FORMATION OF A SCATTERED CITY

EUSTON ST AND STRATA SE1

"Two chief types are distinguishable among large cities: the concentrated and the scattered. The former is the more common in the Continent and is clearly represented in the big government seats of Paris and Vienna, which were the prototypes of European town-planning at the end of the last century. The second type is represented by the English town, which now seems to many of us the ideal"

Rasmussen, 1937

Contemporary London seems a rather illegible continuum of brick, concrete and glass, regularly interrupted by vegetated spots. Endless lines of low rise terraces prevail over any other typology. Their dark pitched roofs and brick chimneys configure a distinctive townscape that can be perceived from the few hills of the city. However, the overall skyline is being transformed, filling it with skycrapers that alter the historically flat profile. The traditional landmarks such as Saint Paul or the Big Ben are outshined by recent business centers and medium rise developments. As Rasmussen suggested, London's urban structure does not follow the typical configuration of European cities. The insular character of England, its flat terrain and, above all, the difficult balance between two antagonistic institutions (the Court, which held the government, and the City, which held the means, i.e. the money) determined London's form until the nineteenth century. Since the Industrial Revolution, it was its character as hub of global trade and head of the Empire which propelled the intensive suburbanization and multiculturalism that defines the modern metropolis. As every historic process, the urban evolution has left a trace in the physical structure, which makes possible the understanding of London from the observation of its much altered profile.

EUSTON TOWER, HOUSES OF PARLIAMENT AND BT TOWER

LONDINUM

Urbanized Area:
127ha

Population:
40,000

Density:
314ppha

Fig.7-2 Current characteristic urban form on Roman and Medieval London. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

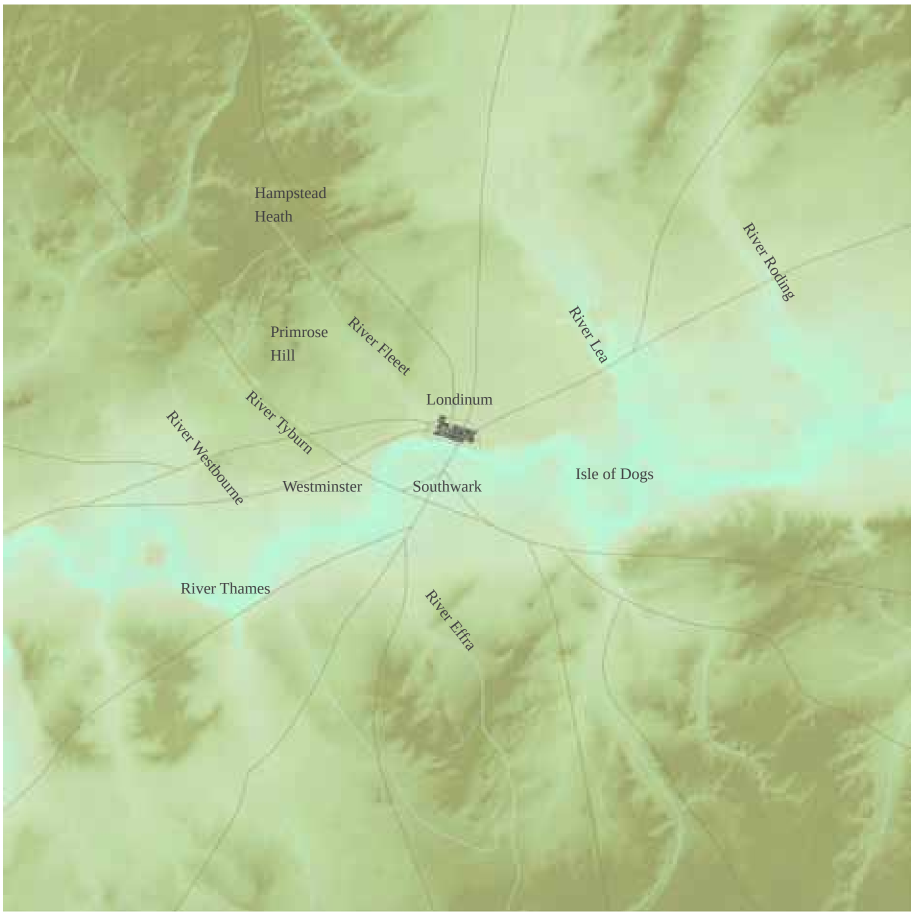


Fig.7-1 Greater London in the Roman period

Fig.7-3 Roman London, overlaid to the medieval layout (based on OS map of Londinum 1981,Lobel, 1989)

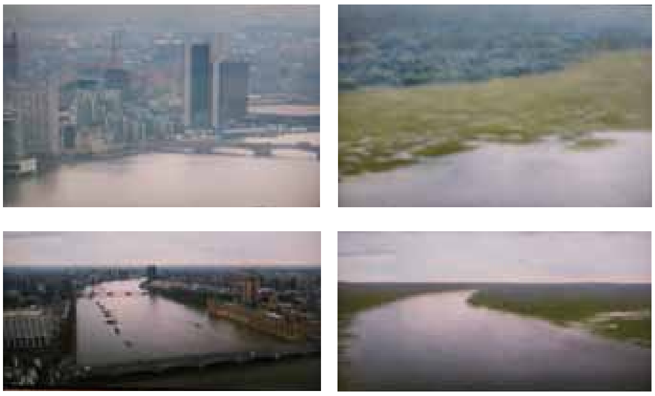


Fig.7-4 The Thames riverbanks were marshlands. The muddy soil prevented development on the south bank during the initial centuries of London history (frames of a film displayed at London Museum)

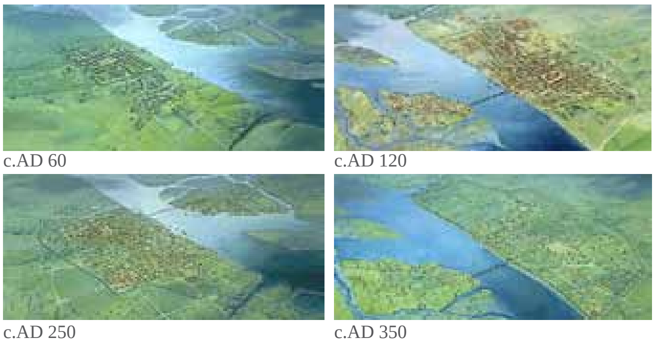


Fig.7-5 Different development stages of Londinum: (Ross & Clarck, 2011)

Fig.7-6 The key urban elements of Londinum: the bridge (top left), the forum (top right) and the wall (bottom)

7.1. The Roman origins

The historic development of London began with the Roman colonization as any previous settlements became significant. The geography of this part of the Thames valley is characterised by vast marshlands, which were regularly flooded and inhibited permanent settlements, except for some areas in the north bank, where the topography provided some protection from the high tides. Before the Romans, the Southeast region was characterized by dense forests which made terrestrial communications slow and difficult. The site where Londinum was built, at the innermost section of the Thames Estuary, had an strategic importance for the Imperial expansion. On the one hand, the tidal effect favored upstream navigation for the ships coming from the continent with legions and goods and, on the other hand, the Thames was narrow enough to allow easy communication between both banks, thus enabling the continuity of the road network.

The imperial colonization repeated the model that had been so successful around the Mediterranean Sea, creating an efficient road network to facilitate the rapid deployment of troops, and an strategic distribution of fortress to consolidate the military prevalence. Londinum was initially one of those fortresses, whose purpose was to protect the river crossing at one of the few points where both banks were suitable for construction (especially in the Southbank, where the riverbank was muddy in most other areas). The fort would not acquire further significance until Claudius' campaigns (AD 43). A decade after this invasion, Londinum was already a thriving market town, "crowded with merchants and goods" and a cosmopolitan population of around 10,000 inhabitants[1]. The early town was characterized as a great communication hub and commercial node, from which troops and goods from the continent could be redistributed across the island.

The location of the emerging city was unrivalled in terms of international trade into the Island. The Thames estuary was aligned with both Seine and Rhine's mouths, which enabled the connectivity with major trading routes in the continent. However, the good communications and economic flourishing also brought about some negative consequences, as not only merchants took advantage of the estuarine approach but also invaders, particularly from the North, who took any opportunity to attack and sack the city. As early as AD 54, London was sacked for the first time by an Iceni tribe from current Norfolk, in response to a violent territorial dispute which ended up in the assault and rape of the widow and daughters of the Iceni King by Roman soldiers. After Boudica's revolt, the city recovered and augmented its commercial role. There are doubts whether it was an administrative centre itself or just the logistic node of province but it is clear that it became the foremost city in

1 Ross & Clark, 2011

7th century

Urbanized Area:
50ha

Population:
5,000

Density:
100pphа

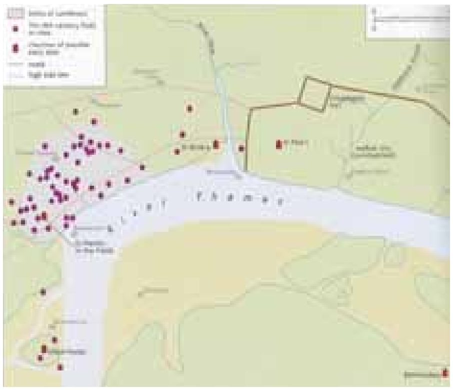


Fig.7-7 Saxon town of Lundenwic as revealed by excavations (Ross & Clark, 2011)

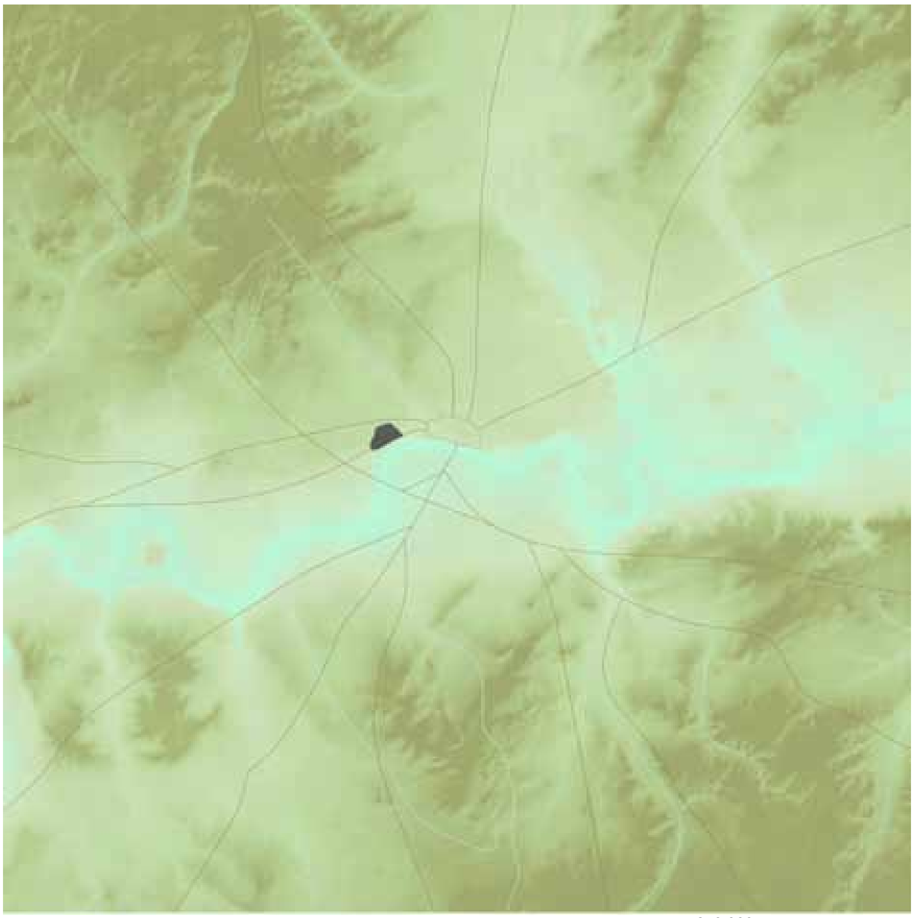


Fig.7-8 Greater London in the Saxon period (6th to 8th centuries)

1:250,000
0 3 6 Km

Britain, reaching up to 25,000 inhabitants[2] and having the largest forum to the North of the Alps[3].

Most of what is known about the Roman settlement has been found out through archeological excavations, which means that current and future digging can raise new theories and dispute some of the current ones. Few reminiscences can be found in contemporary London that reminds its Roman origins, neither the street layout nor public space can be traced in the current city. Only some parts of the wall at Barbican and remains of the riverside wall can still be witnessed on site by the visitor.

Perhaps the most important feature from the original settlement was the radial road network that intersected on it, a critical aspect to uphold the peace in the province. London was at the junction of the main roads, which connected the South East coast with the northern cities of Deva (Chester) or Lindum (Lincoln) and Aqua Sulis (Bath) to the East. Although there possibly were two crossings over the Thames, within a close distance, one at London and the other at Westminster, only the former had a permanent bridge. The need for protection of such strategic bridge required the fortification of Londinum with brick walls, which are dated around AD 200[4]. The walls, the bridge and the road network were the seeds that would germinate in the future condition of the city, although to a limited degree.

7.2. The Saxon period

When the Romans left the island, around AD 410, the native tribes could not sustain the complex organization and rules. The international connectivity of the port was no longer of any use as global trade stopped. Most theories agree on London remaining uninhabited,[5] while the country returned to a previous civilization state, consisting on rather self-sufficient settlements scattered over the territory. Britons ruled for few years as Saxons arrived in 448 to commence a period of invasions and disputes during which Saxon and Briton kings alternated. Only when continental trade was reinstated would London be seen as an strategic location again. In the sixth century, Saxons made London (Lundenwic[6]) the seat of the government of the kingdom of Essex, although the capital

2 Wilson, 2004
3 Ross & Clark, 2011

4 Saint & Darley, 1994 p.16
5 Wilson, 2004 Saint & Darley, 1994 Ross&Clark, Rasmussen, 1937
6 Wic has been interpreted as a term for “port” (Ross & Clark, 2011)

of the biggest kingdom in England remained in Winchester, Wessex until the arrival of William the Conqueror in the eleventh century. However, archeological research seems to indicate that the Roman enclosure had remained uninhabited and the new location was circumscribed to the area between the current Covent Garden and the Thames (which could explain local toponomy such as Aldwich, reinterpreted as Old Wich or old port). Around the eight century, the first Christian settlement and monastery at Westminster were founded.

7.2.1. Return to the Roman enclosure

By the middle of the ninth century, the Danish raids started. It is possible that the threat from the frequent Viking attacks caused the reutilization of the old Roman enclosure. The wall was reinforced and the city was refounded in its original location under the rule of Mercian kings (Alfred the Great was the king of England and his son-in-law, Ethelred, the King of Wessex and Kent). Despite the wall, the city was reduced to ashes and rebuilt a couple times before Danish king Cnut took control over Edmund Ironside in 1015 and forced him to share England kingdoms with him. When Edmund died, Cnut became the king of all England. The last Saxon king, Edward the Confessor, took one of the most important decisions for the subsequent development of London. He ordered to rebuild Westminster Abbey and his nearby royal palace, which became the most important seat of the government in the kingdom (until then, kings used to summon their court on wherever place was found convenient). Almost right after Edward's death, the first Norman king, William the Conqueror, became the first king in the history of England to be crowned in Westminster Abbey, starting a tradition that still persists to date.

7.3. The Norman invasion and the consolidation of London as a center of power

From its origins, London proved a high degree of independence from external powers. Either kings or even the Catholic Church, which chose Canterbury as its central seat in Britain, would ally with the City whenever there was a mutual interest. However, it never became a city-state, like Venice or Florence or the court of absolutist monarchies. When William the Conqueror arrived to London, he neither invaded it nor did he impose a Lord. At contrary, he guaranteed its charters and the City recognized him as legitimate king of England. The preservation of London's support was one implicit purpose behind William's decision to erect the Tower to the East of the wall. The fortification would, at the same time, symbolize Royal protection and power. It was an outlook to control the city while keeping a minimum distance. Westminster consolidated as the seat of the Government, concentrating the main institutions: the Royal Treasure, the Supreme Court and, finally, the Parliament. The proximity of the court was not impediment to preserve the claim of the City of London to self-rule, for one reason: the kings were frequently in need of money, and the City could provide that, normally in exchange of further privileges. Even if kings were tempted to exert excessive demands, London would not hesitate to react with violence if necessary. Its people were not feeble merchants but entrepreneurs used to arms and combat[7].

Fig.7-9 London in the 14th century. The marshy Southbank, the Tower at the forefront, the wall, several buildings on the bridge and the spike of Saint Paul are some of the main features that can be observed from this perspective (Amedée de Forestier, c.1912)

Fig.7-10 The Guildhall. Originally built in 1410. It was the center of civic power at the core of the City

Fig.7-11 The Tower of London represented the Royal presence at the east of the City

7 Rasmussen, 1937 p. 37

16th century

Urbanized Area:
180ha

Population:
67,000

Density:
372ppha

Fig.7-13 Current characteristic urban form on late Medieval London. Southwark area. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

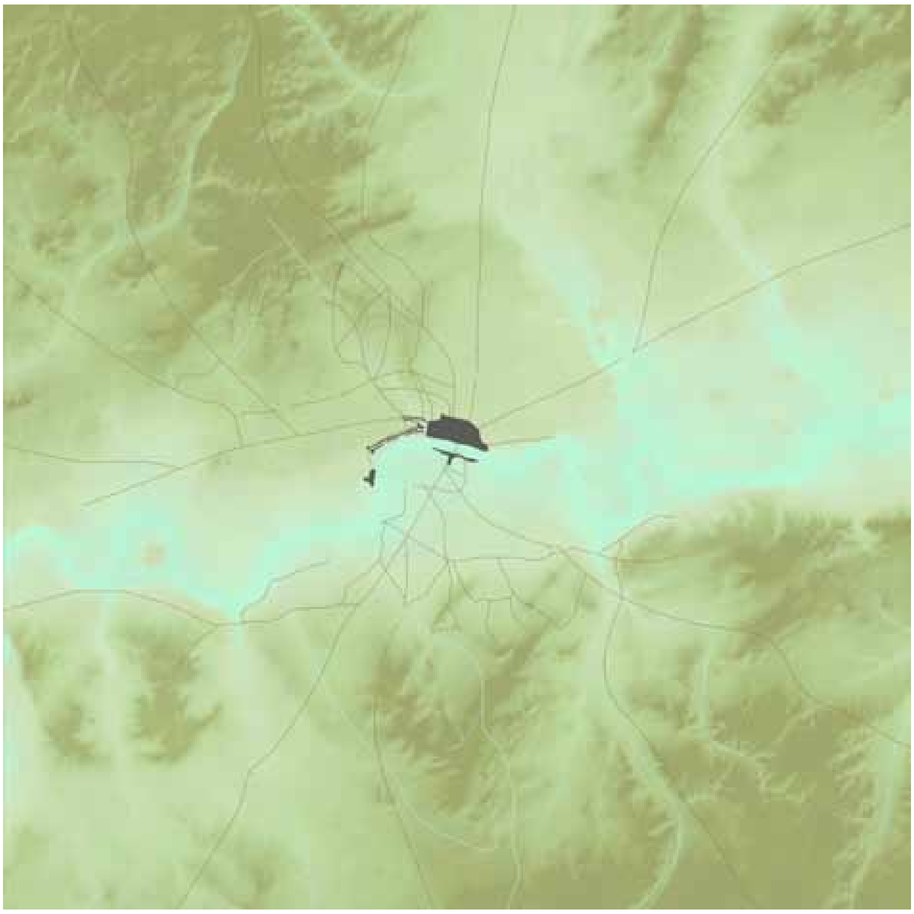


Fig.7-12 Greater London in the 16th century

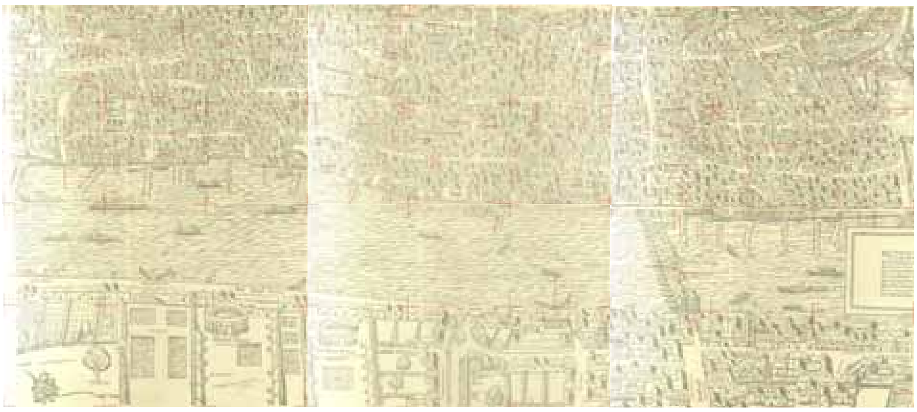


Fig.7-14 “Agas” map showing London during the 1560s (reproduced from Prockter & Taylor, 1979)

Fig.7-15 “Agas” map. Detail

Fig.7-16 Stapple Inn, Holborn. This building, originally from 1586 was restored in the 19th to portray typical Tudor architecture

7.4. Medieval urban form

The physical structure of the city around from this period (11th Century) can be recognized in contemporary London. The City occupied the former Roman settlement, whose wall was preserved and reinforced but, unlike other European cities, it was never moved or replaced by an outer ring. It caused a rapid compaction of the urban fabric. Two miles to the west of the City, Westminster was growing as place of Royal power. Nobles and clergymen built their palaces around the Royal premises as it was usual and convenient to have a second residence in London, close to the government. The two centres of power, the economic and administrative, were embodied in these two poles, which would inevitably encourage the urban development of the space between them. The axis that connected the City with Westminster was gradually occupied by European noblemen and wealthy families. The area currently known as The Strand was an aristocratic district filled with palaces and majestic gardens. At the South of the City, an informal settlement had already been formed around the South fortification of the bridge. It was Southwark, a second class town, associated with spectacles, leisure and, to some extent, vice. Convents and monasteries, particularly friars, were numerous out of the City walls. Their large states prevented urban expansion in the immediate periphery. However, a number of hamlets and villages were blooming beyond the cultivated grounds. Paradoxically, the high density of the city within the wall propitiated the development of these new settlements, which persisted as the low dense suburbs and local boroughs of rural character that are still recognizable in the current Greater London region.

William Fitzstephen described medieval London (c.1170) as a strongly fortified city, filled with palaces, churches and public buildings:

"Amid the noble cities of the world, the City of London, throne of the English kingdom, is one which has spread its fame far and wide, its wealth and merchandise to great distances, raised its head on high. It is blessed by a wholesome climate, blessed too in Christ's religion, in the strength of its fortifications, in the nature of its site, the repute of its citizens, the honour of its matrons, happy in its sports, prolific in noble men...

On the east lies the royal citadel, of very notable size and strength; its court and wall rise from very deep foundations, where mortar mingles with animal's blood...On the west are two keeps strongly fortified...The whole way round the north of the city the wall, tall and wide, strengthened with turrets at intervals, links the seven gates of the city, each double faced... Once London was walled and towered on the south side too; but that great river, the Thames, well-stocked with fish, with tidal flow and ebb, has lapped against the walls over the years and undermined and destroyed them...Two miles to the west of the City, with a populous faubourg in between, the royal palaces rises on the bank, a building of the greatest splendour with outwork and bastions. Everywhere outside their houses are citizen's gardens, side by side yet spacious and splendid, and set about with trees. To the north lie arable fields, pasture land and lush, level meadows, with brooks flowing amid them, which turn the wheels of watermills with a happy sound... There are also in the northern suburbs of London splendid wells and springs with sweet, healing, clear water...Holywell, Clerkenwell and St Clement's Well are especially famous and often visited; and crowds of schoolboys and students and young men of the City take the air there on summer evenings (...) London like Rome is divided into wards; has sheriffs annually appointed for consuls; has a senatorial order, and lesser magistracies; sewers and aqueducts in its streets (...) The only plagues of London are the immoderate drinking of fools and the frequency of fires."[8]

7.4.1. The Tudor London

The Tudor period (1485-1603) was characterised by a remarkable growth in London's wealth, but also by times of turbulence and conflicts, both at home and abroad. New trading routes were opened thanks to the recent discoveries, which placed London in the centre of the new world map. Before the new routes were consolidated, important transformations were taking place in the character and physical structure of the city. The second Tudor king, Henry VIII, well known by his marital issues, was also a prolific palace builder. Both aspects had important consequences for the city. The king proclaimed the schism of the Anglican Church from Roman Catholicism when the Pope refused to declare the nullity of his first marriage with Catherine of Aragon. As a result, most of medieval city's religious precincts were arrogated for secular use, which changed the status of large parts of London. Some of these properties were seized by the King himself, who accumulated over fifty houses, twenty-one in London area, by the time of his death[9]

7.4.2. An incipient global city

The main commercial port in Europe at the time was Venice, which could benefit from political stability, thanks to its insular condition and the strategic location. However, Venice has never been a manufacturing centre. All the products that were traded had been produced somewhere else. London could take advantage of local production, especially woollen cloth. It added a competitive advantage to its newly acquired centrality in world trade. Until the 16th century, the main market for English cloth was Northern Europe, but trade was conducted through intermediaries in the Low Countries, especially in Antwerp. From the 16th century, new companies were set up by royal charters that conferred them the trade monopoly in a particular region. These companies rapidly

8 Saint & Darley,1994 pp 29-30
9 Ross & Clark, 2008

17th century

Urbanized Area:
372ha

Population:
200,000

Density:
537ppha

Fig.7-18 Current characteristic urban form on the Strand. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

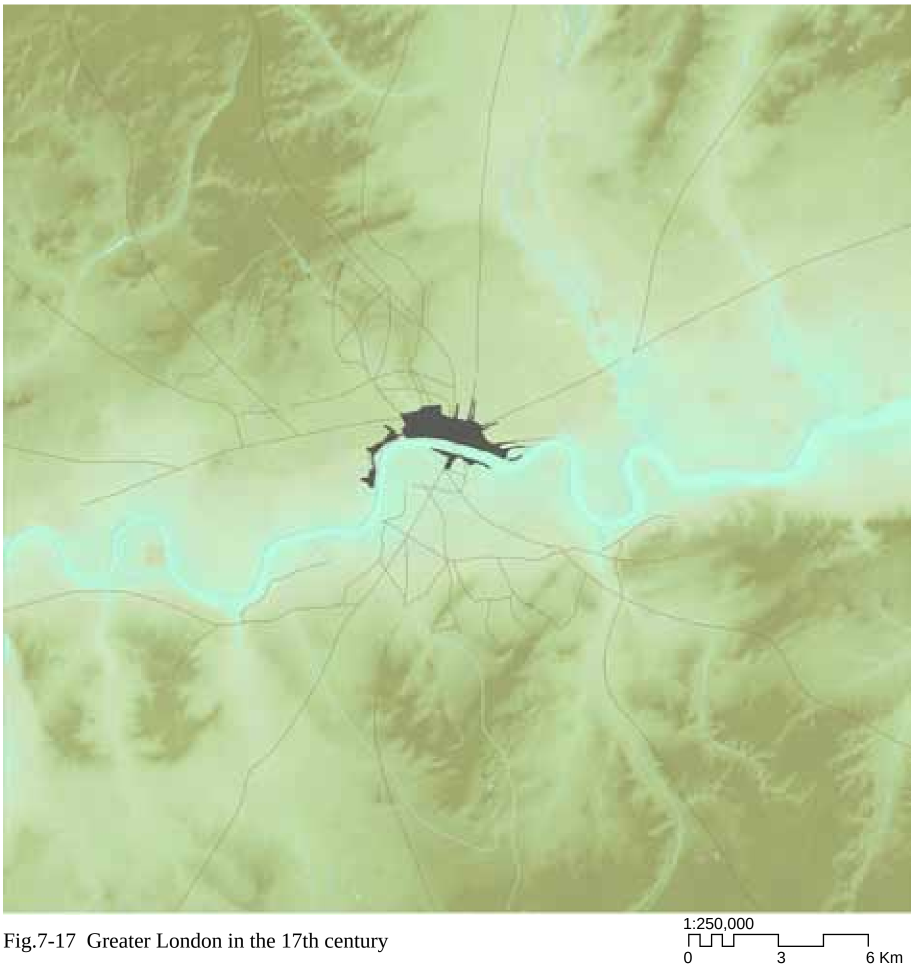


Fig.7-17 Greater London in the 17th century

Fig.7-19 Map of the City of London in 1676 by Ogilby and Morgan. In yellow the area affected by the Great Fire. Most of the city had been rebuilt (source: after British Library Online Gallery)

Fig.7-20 Model of typical timber house before the Great Fire of 1666

Fig.7-21 Detail of Ogilby & Morgan map of 1676 (reproduced from Hyde, 1992)

Fig.7-22 London from Southwark c.1630 (artist unknown,Museum of London)

flourished with investments from private shareholders from the City. They turned into powerful corporations, shipping well armed expeditions to English colonies to secure the exclusive provision of valuable goods and products all over the world. The first chartered company was the Russia Company in 1553, followed by the Spanish Company (1577) and the Levant Company (1581). However, the biggest companies were linked with international trade. The East India Company, which would become the greatest of all of them, was founded in 1600. The entrepreneurship spirit of these companies led the expansion of the British Empire (arguably ahead of royal will) and private initiative positioned London as a paradigm of "free trade"[10]. The increase of maritime traffic made the improvement of navigation in the Thames an urgent priority. A bewildering number of vessels were overcrowded in the so called Pool of London, which made unload operations difficult and facilitated smuggling. The transformation of the banks of the Thames in the most important port of the world was a cumbersome task that stretched over four centuries. The development of the port was as significant as the railway or the underground in the configuration of London as industrial metropolis.

The commercial growth brought about a demographic explosion in the city of the 17th century. The massive flow of immigrants was added to the already overcrowded city. The new population was crammed in peripheral neighbourhoods, where merchants could find cheap labour. Even the artisans were forced to move out of the wall since they could not afford soaring rent prices. Artisans had traditionally sold their products in their own workshops, which required a proximity to the residential areas. However, the role of tradesmen as intermediaries made centrality no longer essential for the artisans, so they left the city. The centre of London became a business zone as if advancing the future character of the medieval precinct as the financial district of United Kingdom.

Despite the high mortality caused by the Black Death during the middle ages, the 17th century city was congested in its medieval layout. The urbanized area extended up to the Thames bank and even the bridge was filled with 4 to 5 storeyed buildings. Most buildings were made of timber, had a gabled roof, bow windows and overhangs that made very narrow streets, which were filled with pedestrians and carriages that could barely circulate. There was no sewage and waste from buildings was sent directly to the streets. Various attempts had been made to control overcrowding but they had little impact. Elizabeth I enacted a law to ban the construction of new houses at less than three miles from the city gates[11] and limited the number of families per dwelling to mitigate the poor conditions of London environment.

The Great Fire of 1666 was an opportunity to reconsider the medieval layout. The fire started on the 1st of September and destroyed around 80% of the buildings of the city, during five days of unceasing blazing. Remarkably soon after the Fire, several rebuilding plans were presented to the King Charles II. Some of the most prominent intellectuals of the time, including Christopher Wren and Robert Hooke, elaborated ideal proposals that embraced the codes and stylistic language of baroque planning. None of the plans would be adopted as reconstruction was already started by residents, using the old plot configuration to erect the new buildings. A code for the reconstruction of the city, based on the work of a committee of which Wren and Hook took part, was passed in 1667. Some of the measures regulated the street width, construction materials or the access to the river. Eventually, the rebuilding of London did not imply dramatic changes on the overall urban structure. The 1676 map by Ogilby and Morgan (fig. 7-11) shows how the area devastated by the fire was already rebuilt, with some improvements but without a trace of the baroque urban ideas that had been put forward in the aftermath of the Fire.

10 Rasmussen, 1937 p.67

11 Rasmussen,1937

c.1720

Urbanized Area:
1,200ha

Population:
625,000

Density:
520ppha

Fig.7-24 Current urban form in Covent Garden area. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

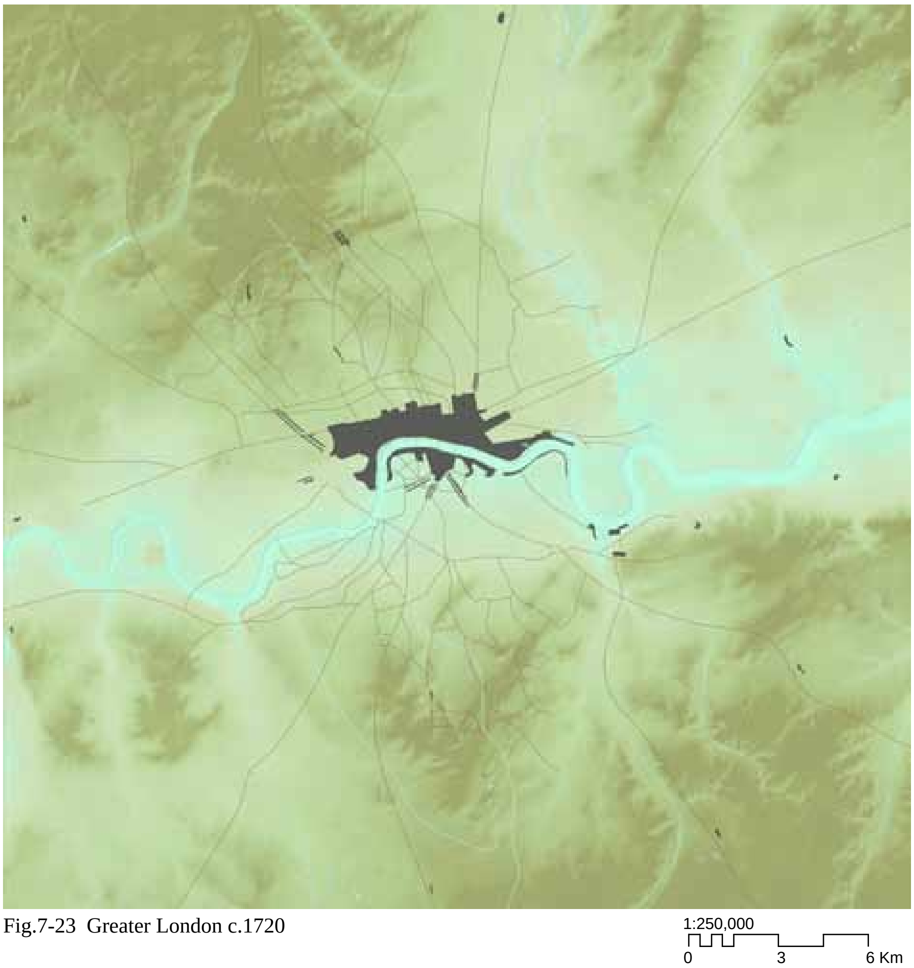


Fig.7-23 Greater London c.1720

Fig.7-25 London in 1720 by John Strype (source: HRI Online)

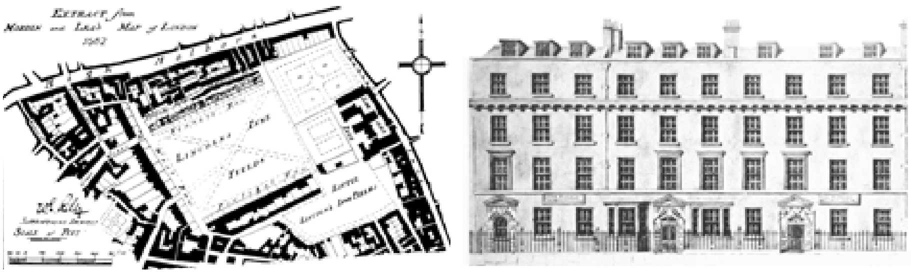


Fig.7-26 Left:Lincoln's Inn Fields in 1682 . Right: Covent Garden, elevation (Riley & Gomme,1912)

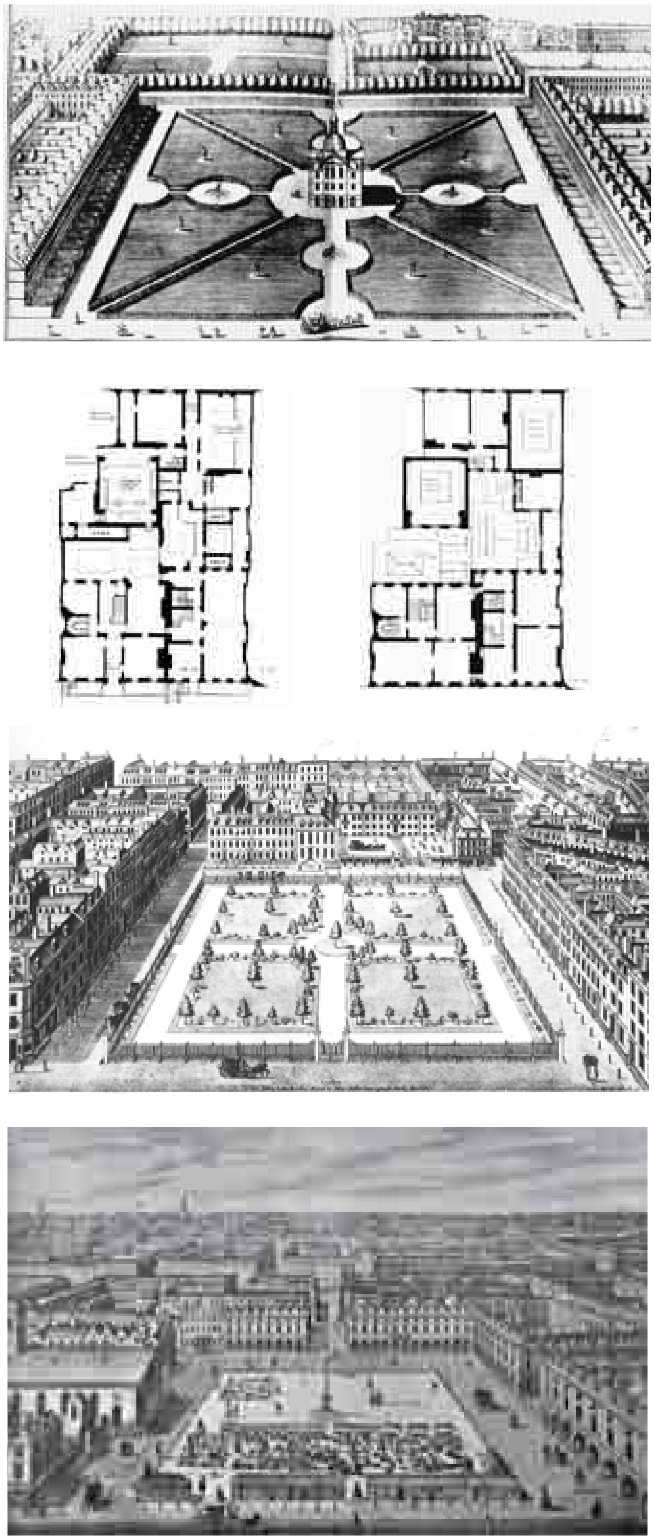


Fig.7-27 Fashionable West End. From top to bottom: Design for the laying out of **Lincoln's Inn Fields**,1699. **Lincoln's Inn Fields**, Plans of number 33&34 **Leicester Square**, 1731 **Covent Garden,** c.1720 (sources: Riley & Gomme,1912 Longstaffe-Gowan, 2012 Library of Congress)

7.5. The different paths of East and West-Ends

In following decades, London became considerably wealthier due to the consolidation of trading routes and the Imperial expansion. The accumulation of wealth was very uneven but the difference between the rich and poor increased notably. The physical city, which had definitively extended beyond the wall, reflected this social segregation in a way that is still present in the character of current boroughs. The congestion and specialization of the old City as commercial centre propitiated an expansion westwards, on land that had been owned by Clerical communities but that had passed to noble landlords after the schism and subsequent dissolution of monasteries and convents. Now that the city had reached their properties, landlords could obtain substantial benefits by developing their states into fashionable residential squares. The standard was set by the construction of Covent Garden in the 1630s, in the grounds of the former Abbey of Saint Peter, which were transferred to the first Earl of Bedford.[12] The plan for the Square was designed by Inigo Jones in a classic Italian style, which is particularly reflected in Saint Paul's church. The favourable reception of the square as location for their London houses of the well-to-do families fostered the construction of many other "fashionable squares" in London West End. Leicester, Bloomsbury, Lincoln's Inn Fields, Red Lion, Soho, Grosvenor, Berkeley, Saint James's, Torrington or, the best preserved of all, Bedford Square were built between the 17th and 18th century. Although many of them are still owned by private landlords (including the open spaces which may even have restricted access) at present time, the maturity of the trees (typically London plane) planted in the gardens can be enjoyed by all contemporary Londoners.

The east of the city was following a different path. New suburbs were mushrooming on the river banks, east of London Bridge. Sailors and nautical suppliers established small communities that grew along other manufacturing industries, such as pottery or breweries, which had settled in the area. East London reinforced its industrial character during the following centuries, particularly in the 19th, with the construction of the new docks. They supported the international commercial activity before the steady decline and definite crisis at the end the 20th century. The marked unbalance between the west and east of the City can still be appreciated in contemporary London.

12 Rasmussen, 1937 p.166

c.1750

Urbanized Area:
1,645ha

Population:
650,000

Density:
395ppha

Fig.7-28 Greater London c.1750

Fig.7-29 Current urban form in Bedford Square. Left-top: **plots**. Center: **buildings**. Above: **aereal image** (photo from Bing Maps)

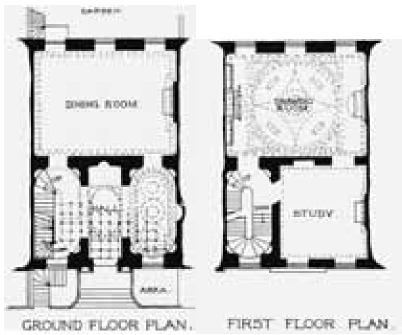


Fig.7-30 Nº32 Bedford Square, ground floor (left) and first floor (right) (Riley & Gomme,1912)

Fig.7-31 Bedford Square**,** East side by Thomas Hosmer in 1851

Fig.7-32 Blackfriars Bridge, 1798 (Museum of London)

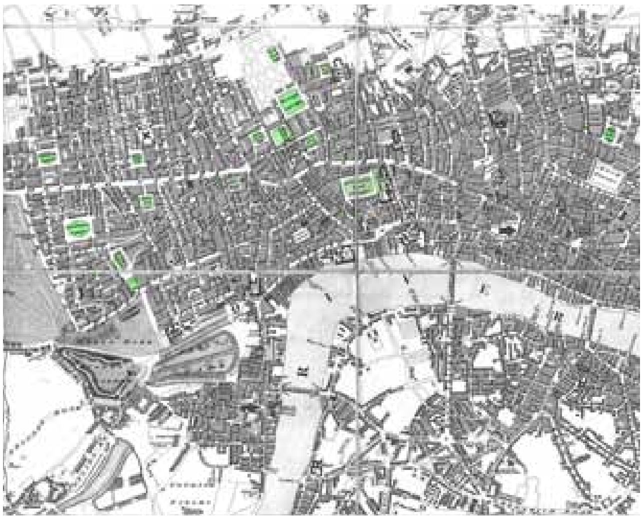
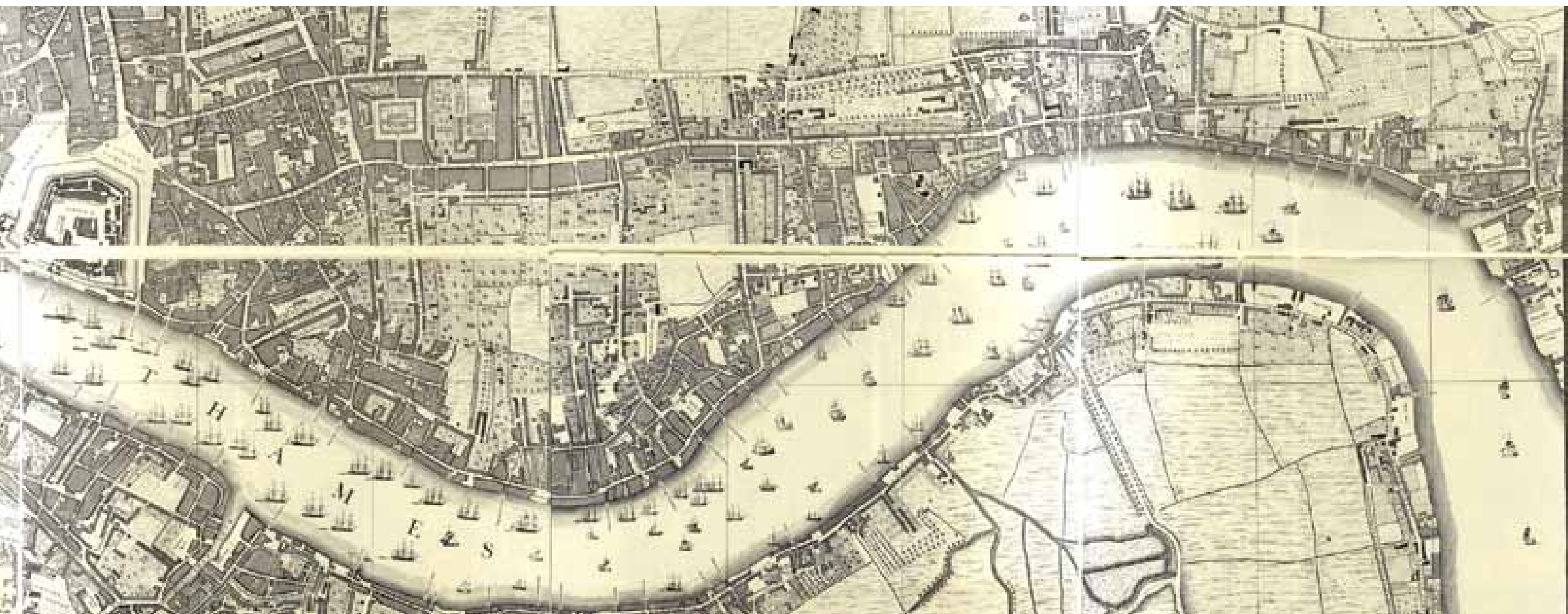


Fig.7-33 Extract from Mogg's map of London, 1809. The main squares of the West-End are highlighted in green. The new bridges are also portrayed in this map

In the 18th century London was the largest metropolis of the world, reaching one million people, and the base of a commercial army with links all over the globe. The economy of London was based on ruthless competition and free market, which made it a city of sharp contrasts. Few restrains were imposed to entrepreneurs, who raised investments for their ventures and increased the overall wealth of the city. The high class could find in London everything that money could afford, from exotic fur or food to fashionable furniture or even slaves to work in their states. The social and cultural agenda was also very active: clubs, academies, coffee-houses, theatres and opera houses provided a variety of opportunities for amusement and socialization. But London was a hard city too. Overcrowded streets could portray the image of sheer misery. Vagabonds, prostitutes, beggars and starving children were quintessential elements in London urban scene. The city that demanded and produced the most luxurious and stimulating lifestyles also brought in extreme poverty and shameful levels of deprivation.

The physical boundaries of the city were spreading at the same level as its economy flourished. The urban growth had two opposite poles: Westminster to the west and the port to the east, which shaped a rather elongated city, stretching along the Thames from current Chelsea to Limehouse, almost reaching the Isle of Dogs to the east. The construction of two new bridges over the Thames was a remarkable event of this period. London Bridge had remained as the only crossing point since Roman times. The fierce opposition from the City had prevented further constructions beyond its boundaries until 1750, when a new bridge was built in Westminster. Few years later, a third bridge connected Blackfriars to the Southbank to reinstate the centrality. London's expansion was however unstoppable. The additional bridges, together with new major roads at the North, helped to create new residential pockets both at North and South. By the end of the century, the city had reached Paddington, the current Euston Road and Islington, while in the Southbank, development concentrated along the axial projection of the bridges.

Fig.7-34 Bottom map: Extract from Rocque's plan of London, 1747 The city extends westwards while river traffic increases(reproduced from Hyde,1982)



c.1835

Urbanized Area:
3,157ha

Population:
1,878,000

Density:
514ppha

Fig.7-36 Current urban form in Regent's Street. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

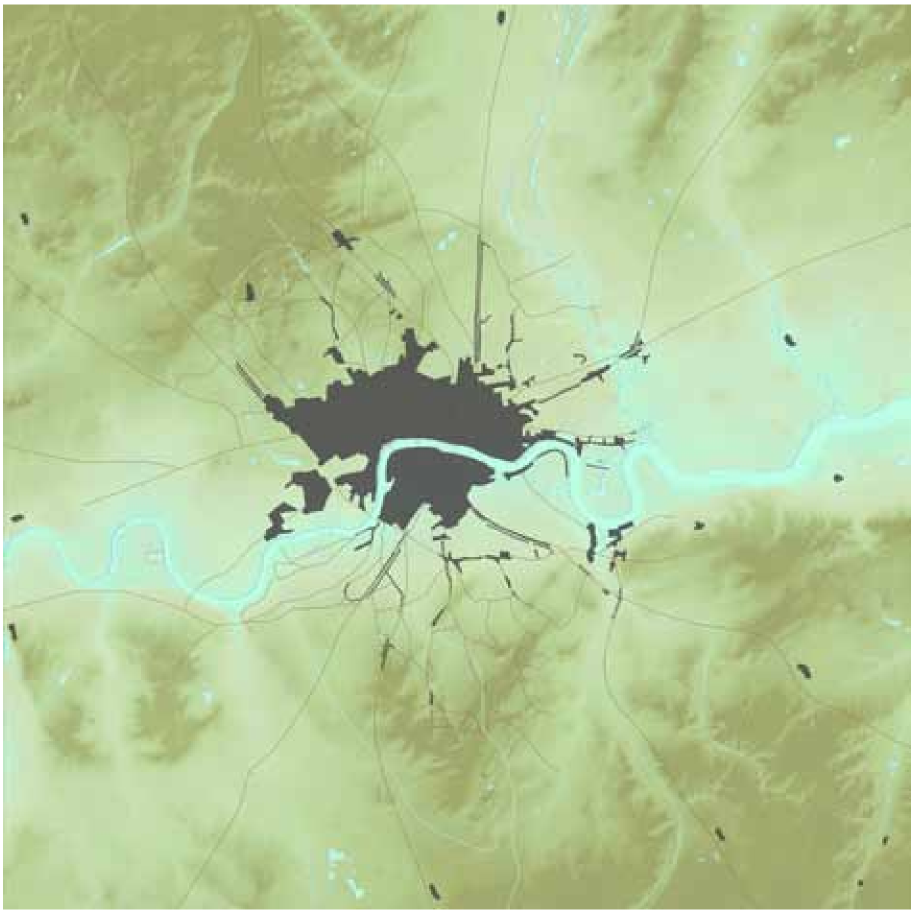


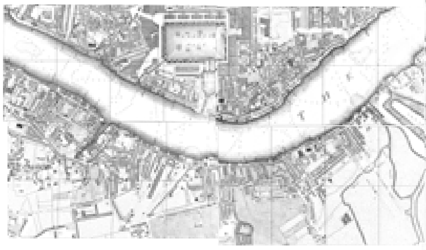
Fig.7-35 Greater London c.1835

Fig.7-37 Current urban form in Commercial Road Top-left: **buildings**. Top-right: **plots**. Bottom: **aereal image** (photo from Bing Maps)

Fig.7-38 Chimneys and river congestion indicate the advent of a new age. The Rhinebeck Panorama of London, 1810 (Museum of London)

7.6. The Industrial Age

The 19th century started with a period known as the Regency, when the Prince of Wales acted as regent during George III's periods of insanity (strictly speaking 1811-1820, although the term is normally extended until Queen



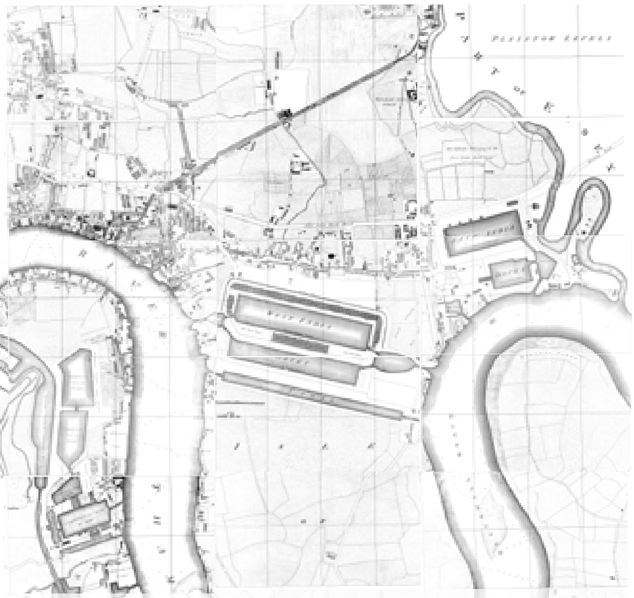


Fig.7-39 Industrial facilities concentrated at the East End, taking advantage of good river access and the new docks under construcion. Extract from Horwood's map of London, 1813 (Laxton,1985)

Victoria's coronation in 1837). The Industrial Revolution and scientific enlightenment were having their heyday, which brought about broad consequences for London's environment. Despite growing competition from northern cities (Glasgow, Liverpool, Manchester...) London remained as one the main manufacturing centres. The cheaper labour cost in other cities was outweighed by the proximity to one of the largest single markets for manufactured products. Large industries clustered around the river, where they had direct access to imports from across the world. Brewing, distilling, leather and shipbuilding factories dominated the landscape of the early 19th century London's East-End. Overseas traders soon required new facilities to satisfy the increasing maritime transport. New docks were opened one after the other under such pressure that they became an investment commodity. Speculation created high expectations and unaffordable operating costs for trading. A dock construction bubble was being fuelled. On the other hand, the worst excesses from Industrial Revolution on the social structure were not yet evident. Slums were still at a seminal stage, in comparison to what they would become at the turn of the century and, although there was deprivation, the general population was not fully aware of its extent until some decades later.

The steady rise of factory smokes over London skyline was partly counteracted by urban improvements, many of them derived from technologies brought by scientific discoveries. Gas lighting, iron water pipes or stone pavements made streets a bit cleaner and a bit safer. The West-End benefited from the most intensive programme of public works. It added an aristocratic character to the fashionable, but mainly bourgeoisie, district. John Nash, the architect of the Crown during George IV regency and reign, developed the magnificent projects that transformed the area to the north of Westminster. A new urban scene was created from Carlton House in Pall Mall (Regent's home) to the new park in Marylebone. The expensive mansions that were already in place prevented a tabula rasa and the design had to be adapted to the existing fabric. Instead of axial thoroughfares and direct views, Nash's plan was divided in sections that created an original and fluid composition. Carlton Terrace marked the beginning of a sequence, in which the nodes were highlighted with circus (Piccadilly and Oxford) or articulations (All Souls church and the Quadrant) and the final destination was the great legacy of George IV to the citizens of London: Regent's Park.

c.1895

Urbanized Area:
12,770ha

Population:
5,572,000

Density:
436ppha

Fig.7-41 Current urban form in Kentish Town. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

Fig.7-40 Greater London in 1895

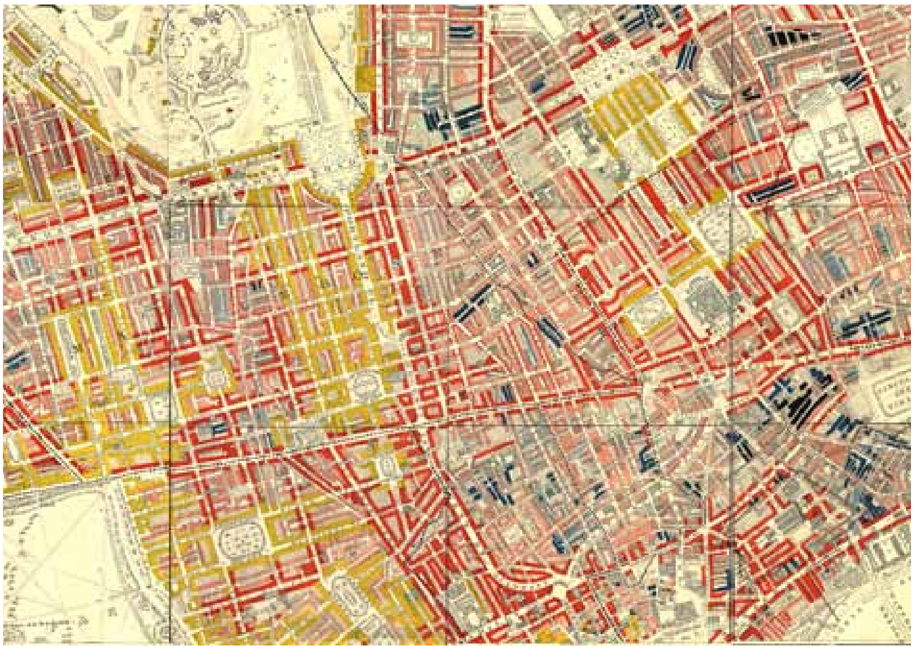
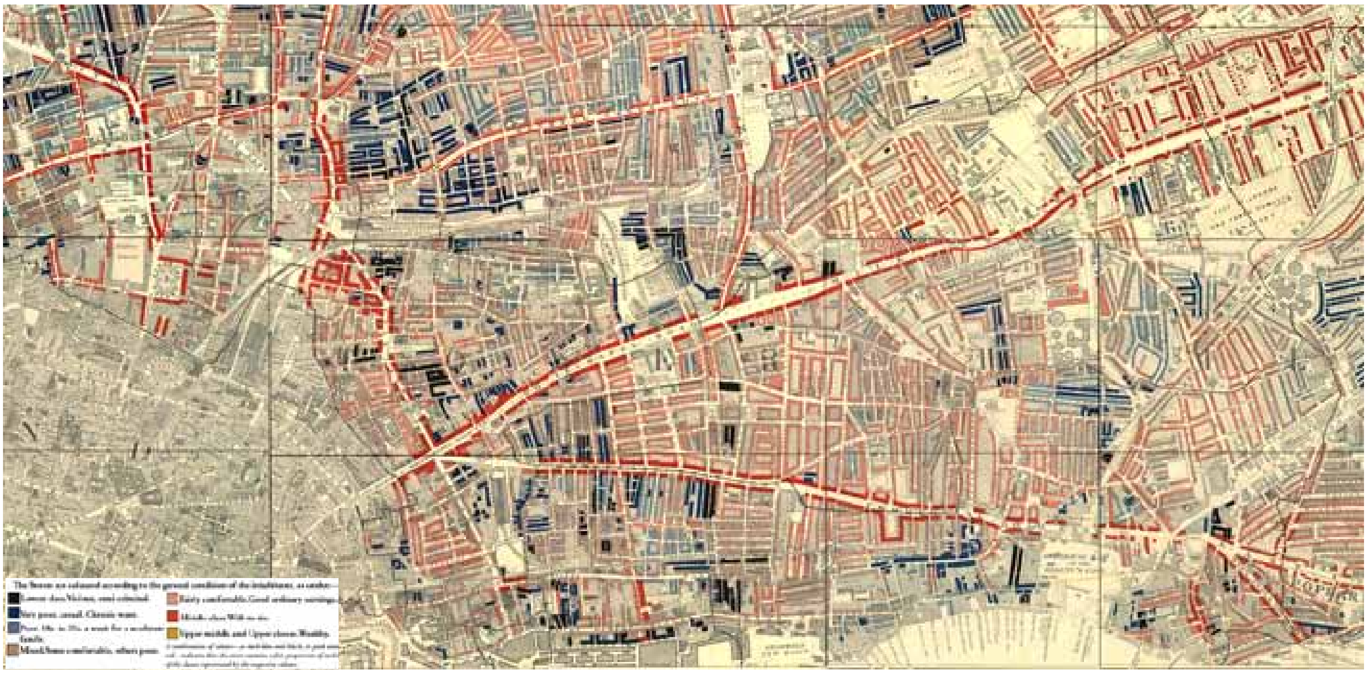


Fig.7-42 Charles Booth's Map of London Poverty, 1889. It confirms the West End (above) as the wealthiest area and the deprivation pockets at the East (right page). Source: University of Michingan

During the second half of the 19th century, Londoners became aware of the evils from Industrial Revolution. London's population doubled from 1831 to 1871[13], from 1.6 to 3.2 million inhabitants. The city was overcrowded and the housing stock was insufficient and inadequate to accommodate the flow of working class immigrants. Initially, the wealthier sector of the population did not pay much attention to the appalling living conditions of workers, who were crammed in unsuitable and insalubrious slums. However, the social pressure arose when epidemics, such as cholera, started to propagate to middle and high-class neighbourhoods. The need for action required an efficient management body that could undertake city-wide operations. The old parish-based system was inadequate to coordinate large scale action in the context of a fast growing metropolis. A new management model was first tested with the modernization of the sewage system, which was managed by the Metropolitan Commission of Sewers, and it was then extended to law enforcement (Metropolitan Police) and public works (Metropolitan Board of Works). The new sewers prevented polluted water being poured into the potable water supply and, eventually, mitigated the problem with cholera. The shortage of housing persisted though. Working class families had often to share dwellings and beds, and those were the lucky ones. A Metropolitan Association for Improving the Dwellings of the Industrious classes promoted housing block prototypes in St. Pancras, Bloomsbury and Pentonville, but these were just isolated examples. The philanthropic Peabody Trust opened a first housing estate to provide decent homes to the poor in Spitafields in 1862. The charity became one of the most active in London, and it manages around 20,000 dwellings at present time.

The poor quality of the urban environment in central London, affected by pollution, noise and frequent episodes of pestilent odours from the Thames pushed middle class to the suburbs. The railway network extended rapidly and reduced journey times between the centre and the periphery, favouring the initial suburban expansion. The construction of Victorian suburbs was fragmented and unplanned. They were colonized by upper middle classes first and, when density increased and the houses got debased they moved further away. The old houses were then rented to lower classes, which could access these areas thanks to cheap trains. Victorian developers had found a model that would be repeated relentlessly. The semidetached Victorian house was reproduced like an industrial product. A high standard of ordinary dwelling[14] that was easy to sell and took over the suburban's landscape. However, the single family houses were divided into smaller units to such an extent that single bedrooms could be rented to entire families. The formerly idyllic suburb was transformed in a slum just by increasing its density in two ways: in built up area but also in the number of persons per bedroom.



13 Ross & Clark, 2011

14 Rasmussen, 1937 p.302

20th century
1st half

Urbanized Area:
62,227ha

Population:
7,387,000

Density:
118pphа

Fig.7-44 Current urban form in Camden Town. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

Fig.7-43 Greater London in 1914

Fig.7-45 County of London road plan aimed to respond to the rapidly increasing traffic, reduce the number of accidents and preserve existing communities free of through traffic (Forshaw & Abercrombie 1944)

Fig.7-46 Social and Functional Analysis by Arthur Ling and D.K. Johnson for the London of London Plan (Forshaw & Abercrombie 1944)

7.7. 20th century London

By the turn of the 20th century, London was the capital of the greatest Empire and the first world city. The population was growing at a remarkable rate: 4 millions in the 1880s, 6 millions in 1901 and 8 million by 1931[15]. Since the year 1800 until the 1930s, London's population had double every forty years. The governance of such metropolis required a different type of organization. The old parish system and district boards were replaced by the London County Council (LCC) and twenty eight borough councils in the last decade of the 19th century. The central areas were getting specialized functions, the City had become the financial and commercial district, the West End concentrated retailing and entertainment, Westminster and the Strand were filled with institutional buildings (now also representing British interests in Colonial departments), the East End and the Lea Valley were the industrial zones and all new residential areas were being developed as low dense suburbs.

The Imperial apogee left its mark in London's landscape, not only in the new Governmental buildings in Aldwych and the Strand but also in the customs and lifestyles of its habitants. The mass of wealthy consumers was an attractive incentive that encouraged the first department stores in Oxford Street, Knightsbridge and Regent's Street. The population of the central boroughs started to decline in the 1920s. They were moving to the suburbs, taking advantage of the underground (the tube) and suburban trains. Rasmussen, a Danish architect who wrote one of the better descriptions of London, exemplified the typical suburban development model with Hendon and Edgware[16]. The London Underway Railways anticipated the demand for traffic by laying new lines towards Greenfield sites which, thanks to the improved access, became attractive to developers and residents. Since the lines would not be profitable until a town was consolidated, the transport companies marketed the destinations with posters and advertisements that have transcended their initial purpose and have acquired the category of art. In this period, industries also started to relocate at the periphery, especially in the West of London since the new type of corporation required vast plots that were too expensive or too difficult to find at the city centre.

15 London Datastore
16 Rasmussen, 1937 pp.350-353

Undoubtedly, the most important events in London's 20th century chronicle were the two World Wars. The World War II was particularly destructive. Over 31,000 bombs[17] targeted the docklands and its strategic facilities, but bombs reached every other corner of the city. Before the end of the war, the reconstruction of London was already being planned. The LCC had appointed Patrick Abercrombie, professor of Town Planning at the University College London, to work as consultant with J.H Forshaw, the Council's architect in the elaboration of an advisory plan for the County of London. Almost at the same time, Abercrombie was also commissioned by the Minister of Works and Planning to prepare a comprehensive plan for Greater London. The plans aimed to propose efficient remedies to four main defects in the pre-war city:" traffic congestion, depressed housing, inadequacy and bad distribution of open spaces, and finally, the jumble of houses and industry which showed itself in a general tendency towards indeterminate zoning"[18] In addition, there was a remark about the lack of architectural coherence that characterized last decades' London development, which should be addressed, according to the planning team, by extending the models that had been applied in public housing estates. The main priority of Abercrombie's plans was decentralization, both to alleviate congestion and to control the "Great Wen"[19] The London County Plan proposed limits to density in the central districts. A maximum standard of 75 persons per acre (185 ppha) was set as the threshold target. It would imply mass household displacements from the centre to the periphery. Moreover, the need for new public facilities (schools, libraries...) would also require changes in land and buildings use. The Greater London Plan was consistent with decentralization (as they shared authorship). It introduced a metropolitan Green Belt and eight new towns to balance the housing loss in the central districts. There is an evident influence from Garden City movement and the particular English fondness single one-family houses. These plans were not legally binding though. They were part of a set of advisory plans that were commissioned to prepare the post-war reconstruction[20]. However, they had a broad support, partly because there was no other choice than to supply new housing, provide amenities and control pre-war sprawl.

17 BBC 2012
18 Forshaw & Abercrombie 1944
19 Foley, 1963
20 Ibid, p.43

20th century
2nd half

Urbanized Area:
70,453ha

Population:
7,172,057

Density:
102pha

Fig.7-48 Barbican Estate, post-war development. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

Fig.7-47 Greater London in year 2000

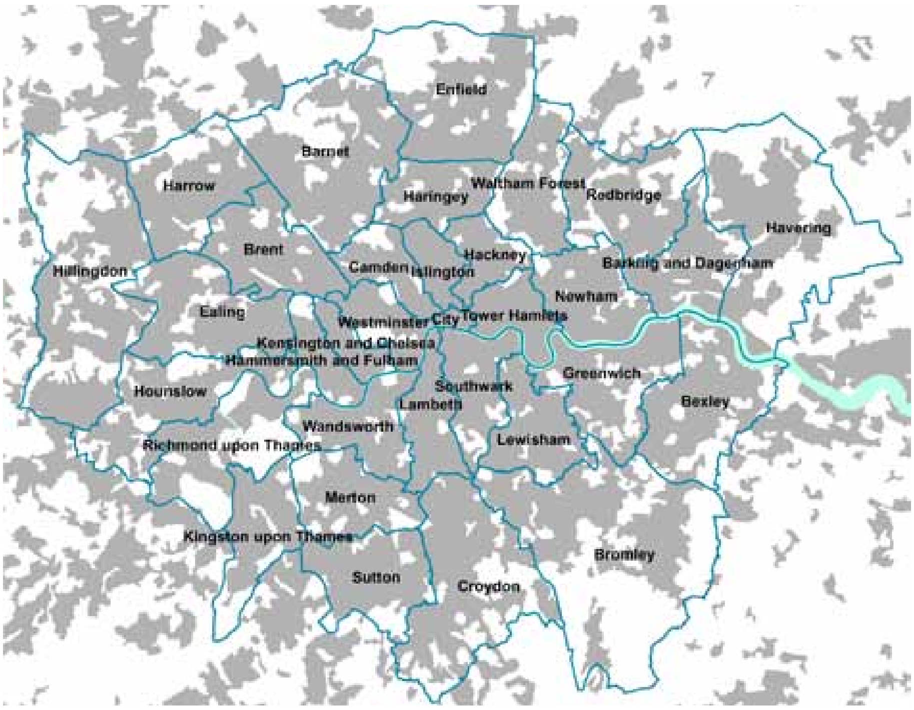


Fig.7-49 Greater London boroughs. Political boundaries and urbanized area (contains Ordnance Survey data © Crown copyright [2012])

Fig.7-50 This scale model of central London displayed at The Building Centre (buildingcentre.co.uk) reflects the changing skyline of the city as it is regularly updated with current projects, which are shown as white pieces. Left: Isle of Dogs. Center: Olympic site. Right: the Shard and the City new skycrapers

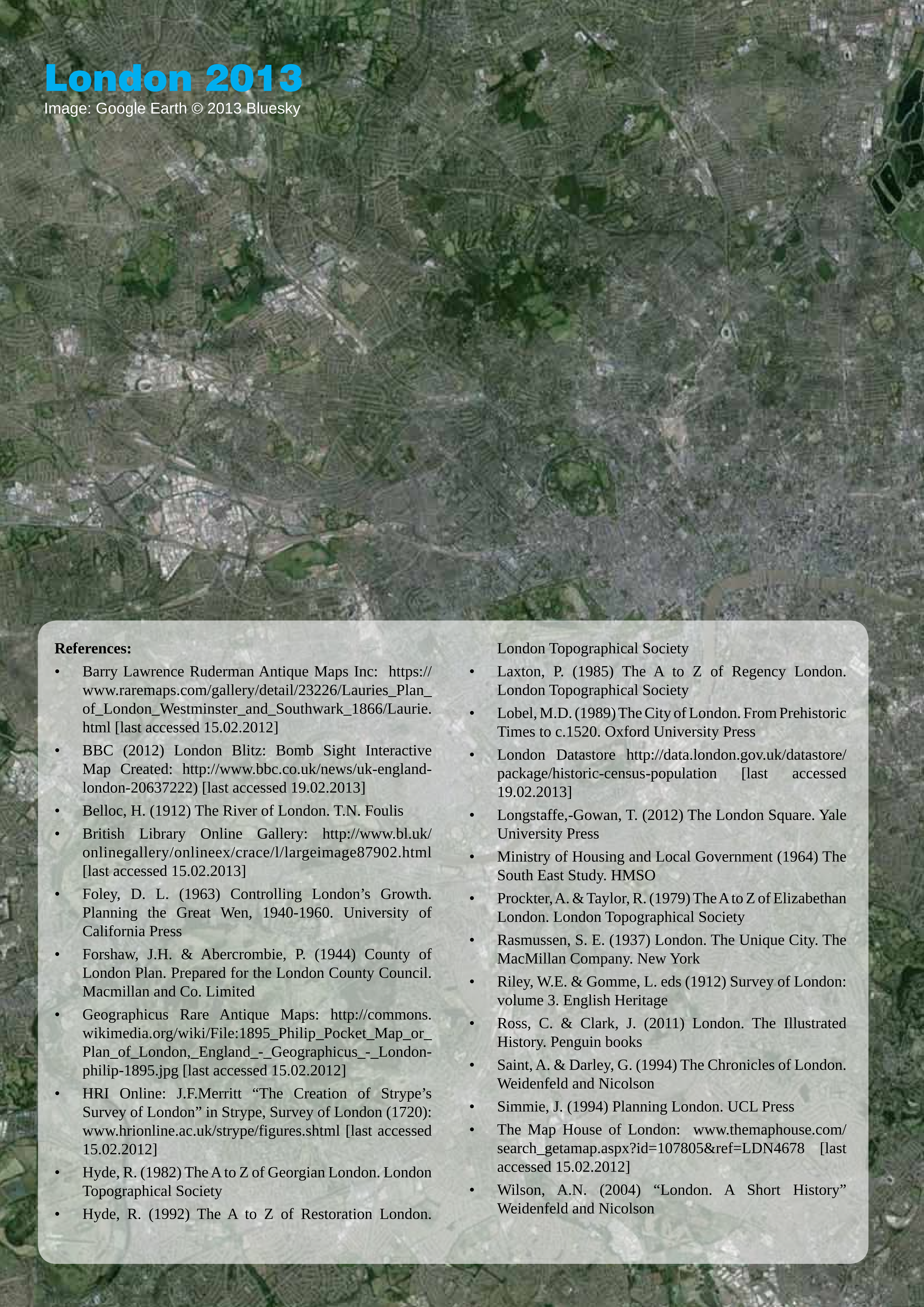
The enactment of the Town and Country Planning Act of 1947 (and later supplementations) enabled the implementation of the concepts and ideas advanced in Abercrombie's advisory plans. It provided for the preparation of development plans by county and borough councils. Development plans were the official documents to guide the physical development of the area for a period of about twenty years. The problem in London was that the extension of the Greater London Plan did not have an equivalent administrative body. The responsibility was divided in six counties (London, Middlesex, Hertfordshire, Essex, Kent and Surrey) and three county boroughs (West Ham, East Ham and Croydon). Each of those had to prepare a development plan and administrate planning controls. The coordination at regional level was exerted by the Ministry of Town and Country Planning but on an advisory status only. The plans also failed to recognize some of the post-war employment and demographic trends. Abercrombie had assumed that no new industry would be admitted to London, but he could not expect an employment growth based, not in manufacturing but in service and office jobs, as it happened in the fifties[21]. Residential decentralization actually occurred but an unpredicted growth in jobs density in central districts enhanced commuting to central London from the outer rings. Out of the ten proposed new towns, only two (Stevenage and Harlow) were developed in the proposed sites. Other six were established in different locations. The Greenbelt was firmly established in the 1960s, close to the Greater London Plan prescription, although a bit outer and wider in some parts. It aimed to present a barrier against continuous sprawl, to reserve agriculture and provide amenity in a more natural environment. The Greenbelt is occasionally spattered with settlements (e.g. Watford) and the road network both radial from London and ring roads around it. Overall, predictions regarding population and jobs trends in the outer ring were far too short when compared to the actual results. From 1952 to 1961 the outer fringe gained 421,000 jobs and 891,000 residents, an increase of 47 and 26% respectively. The densification of the suburbs was inevitably followed by an increase in commuting journeys to central London.

In the 1960s a new administrative structure was established in order to coordinate actions to strategic and local scale. A two-tier system of local government, one at borough scale and other at regional scale were given complementary powers to revise and carry out planning policies harmoniously. The transformation of the political boundaries of London region merged many formerly independent districts and created new ones, not without social and political tensions. After much debate, the Greater London Act of 1963 provided a statutory definition of the Greater London Council (GLC) and the 33 London boroughs (including the City) that it comprised. The GLC replaced the outdated London County Council (LCC). It would be abolished in 1986 by a conservative Government (led by Margaret Thatcher) that understood that decisions about London were a matter of national interest. The history of the GLC was resumed in year 2000, after the Greater London Authority Act 1999 (GLA). The current boundaries of the GLA reflect the extension of developed land in 1938, which has been deemed as an arbitrary and obsolete definition of the real land area of London.[22]

The sixties and seventies were uncertain times for London. Post-war shortage and austerity seemed overcome in the 50s, and the emerging service-based economy was to provide new quality jobs for the new generations. However, the industrial decay was stronger than anticipated and new sectors could not replace the job loss in manufacturing. The closure of factories and derelict industries became part of the landscape. Competition from Far East countries, which were experiencing their own industrial revolution and the cease of privileged commercial networks within the Commonwealth were some of the reason behind deindustrialization. The hopes of the economy were put in tourism and office work, but recovery proved a hazardous task with ups and downs, until the eighties. The demographic growth of the previous decade had slowed down in the sixties, but the conurbation was spreading farther and farther while the central boroughs continued to shrink. By the end of the seventies, the government recognized the inner-city problem. The urban regeneration of former industrial areas became a priority, not only for the local boroughs but also for the central administration.

21 Ministry of Housing and Local Government, 1964

22 Simmie, 1994



London 2013

Image: Google Earth © 2013 Bluesky

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THE CITY

MELLISH ST

DOCKLANDS IN LONDON

MUDCHUTE PARK AND CANARY WHARF

Docklands today

The recent story of London Docklands is well documented and it has been described from different perspectives. Journalists, sociologists, economists, planners or architects have paid close attention to the sequence of events that transformed a decaying area of East London into a thriving business centre. Any visitor that pops out from the Canary Wharf Jubilee Line Station, in a weekday, sometime between 12 and 5 p.m. will witness a frenetic activity. Thousands of businessmen and clerks transit the station and the square. Some are smoking or having informal meetings at one of the coffees near the canal. Others are tourists that have just finished their shopping and are taking some pictures with the 1 Canada Square (once the tallest building in United Kingdom) as background. At six p.m., local pubs are buzzing because crowds have gathered to enjoy the evening beer. If the observer walks away, through the Isle of Dogs, he would witness a world of contrasts. There is a diversity of housing types, from brand new glassy skyscrapers to Victorian terraces, although the private condominium type prevails. To the south, a large park with its farm and sheep offers a sheer contrast respect to the previous scenes. At the other side of the Thames, the Baroque perspective of Wren's Greenwich Hospital and the Observatory are reminders of the long and agitated history of the city that was once the centre of the world.

THE ISLE OF DOGS

CHAPTER 8

DENSIFICATION IN A POST-INDUSTRIAL SCATTERED CITY: LONDON DOCKLANDS

CANADA SQUARE

ROYAL DOCKS

Baroque perspectives had a theatrical intention. They aimed to recreate an stage. The observer should focus on the elements pointed to him by the composition. A similar awkward feeling can be perceived in the Isle of Dogs. A certain lack of urbanity, as if it was a preset stage that is dismantled every night. Despite the attempts made by the Canary Wharf Group, the landowners of the financial estate, to create some night life, the place becomes desert after dusk, as the rest of the island. On weekends, the isolation increases, a reduced number of transport lines connect the Isle with central London. There are few people in the street, not a soul in Canary Wharf. Only in the older communities, at Cubitt Town, Easferry Road or south of Mudchute Park, the streets show some activity. The insular feeling is now overwhelming.

Current Docklands is a world of contrasts. Little has remained from the heyday of Imperial trade. Only the constant proximity of water, flowing on the Thames or encapsulated in the old Docks will remind us of its past. However, the transformations in the urban landscape have erased most references of Industrial and Maritime Heritage. Although some warehouses have been restored and cranes were brought to the West India Dock, the urban scene is, in general, composed by awkward juxtapositions. The integrity of the Docks has been subdued to the needs of the property market. They have been filled, traversed and divided in order to increase the land for development. In other cases, shiny office buildings have been erected right at the water edge or even projecting over the basin (e.g. Heron Quays). Unlike the City or the West End, there is no trace of an old urban structure or street layout. Instead, the area presents a sequence of self-contained enclaves, each with its own character and completely detached from the contexts where they stand.

It may be, however, a considerable improvement respect to the depressive reality and darker perspectives that threatened Docklands in the 1970s. At that time, it would be unconceivable to think of anyone wishing to buy a property or to open a business on such a desolated place. From a purely physical perspective, the success of regeneration is unquestionable. From an environmental point of view, the land has been decontaminated and important pollution sources (ships engines, factory smokes and chemical products) have disappeared. A pool of well paid positions has been created and local residents can now benefit from educational and health premises and a wider range of convenience stores and other facilities to facilitate mundane but essential needs.

The rebirth of Docklands has paralleled the recovery of London as a whole. Indeed, it has arguably played a fundamental role in reinforcing the position of London as economic centre and a world city. The competition from Paris and Frankfurt, especially after the deregulation of the financial market, triggered a strong demand of office space, which the City alone could not supply. Docklands was a massive reserve of land at a prime location, which could be readily available, provided that there were keen developers.

8.1 The city and its port

Whether London grew up as international node because of the presence of the Thames or, conversely, the Thames became of such high importance in global commerce because it enjoyed the large and wealthy market of London, is debatable. For many authors, the explanation for London greatness is fundamentally based on its privileged location[1], with direct access to main European markets through Seine and Rhine's estuaries and, since the 16th century, in the centre of the new World Map. Other chroniclers have found it as a rather vague explanation that would not sustain a thorough analysis. Belloc[2] observed that London was actually ex-centric to the main European highways and it was no better positioned for overseas trade than any of its competitors, both in England and in the rest of Europe. He argues that, as important as its geographic location, there are at least four other reasons that help to explain the maintained prevalence of London over the centuries. Two reasons are geographical and refer to the "ease of approach from without" and what he calls "draining power from within". The ease of approach was possible due to the distance from open sea. Calm water facilitated loading and unloading while the water channel was wide enough as to provide berth to numerous vessels. The draining power was fostered by the road network that converged in London, bringing wool, first, and coal, later. The Southeast of England had a fertile and productive soil, much more than the Midlands or the Northern regions. London was at the "centre of gravity of such area". The two other reasons were socio-political: first, the relative political stability. It was partly provided by the economic royal dependence, which prevented the same kind of absolutism that ruled other European countries. The second reason laid on the "natural tendency of Englishmen for adventure and exchange".[3]

Certainly, the Thames has been fundamental in the history of the City, from Romans to present time, not so much as a scenic background but as an economic asset. London has enjoyed the synergies between maritime trade and a large and wealthy society over the centuries until the second half of the 20th century. When the new economic scenario wiped out all the advantages provided by the river and made most of the port facilities to become obsolete.

The earliest evidences of the existence of a port are dated in AD 52[4]. The first quays served to trade with other Roman provinces and they stretched over 650 meters, from current Cannon Street to east of the Custom House[5] (fig.8-1). Massive oak beams were used for construction and, due to the short lifespan of the wood in those conditions, they were regularly rebuilt, not in the same position, but a few meters towards the water current, thus extending the waterfront progressively. Before the first river wall was built, the Thames was about 100 meters wider than it is today. The main advance in the line of the riverfront was undertaken between 10th and 15th centuries. The wharves of medieval ages were made by individual property owners and for that reason they presented a broad divergence in the quality of construction and materials. Technology was however slowly evolving and, in the 14th century, the first river walls made of masonry were built. A century later, stone became the main system in wharf construction[6]. It meant, among other things, that the need for replacement was less frequent and the advance over the Thames was halted. The medieval port was dominated by the London Bridge. The Roman timber structure had been replaced by a new construction, made of stone between 1176 and 1209. It was packed with houses and shops and it had a drawbridge to allow large vessels to pass upstream, although by the end of the 15th century it was not functional for larger vessels, which had to be confined to east of the bridge, in an area later known as the "Pool of London" (fig. 8-2).

Fig.8-1 The Medieval Quays overlaid on the Roman riverfront (after Lobel, 1989)

1 e.g. Rasmussen, 1937
2 Belloc, 1912
3 Ibid, p. 83
4 Ross & Clarck, p.36
5 Ibid
6 Ibid

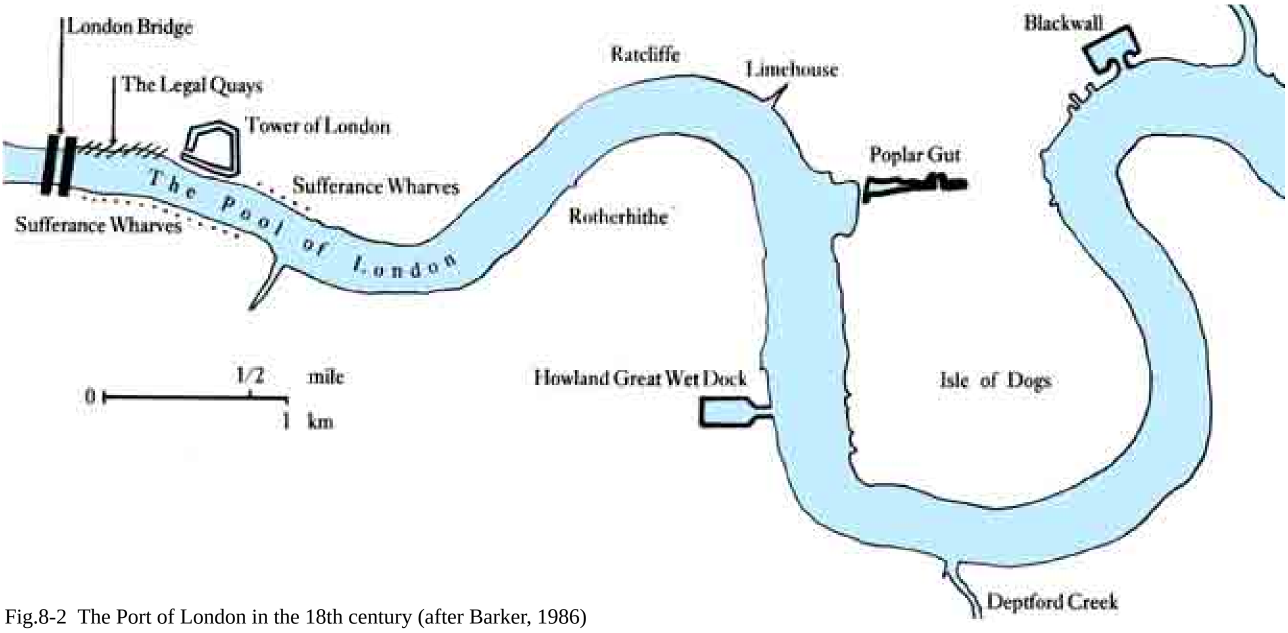


Fig.8-2 The Port of London in the 18th century (after Barker, 1986)

8.1.1. Private initiative in the shaping of Docklands

In the second half of the 16th century, under Elizabeth I's reign, a Royal Commission was set up to regularize the wharves where all goods entering the port should be unloaded[7]. These "Legal Quays" were designated along the north banks between London Bridge and the Tower. They quickly became obsolete due to the great pressure from colonial trade. Additional wharves were opened in the south bank and to the east of the Tower: the "Sufferance Wharves", but these additional 1,000 meters were not enough to satisfy the relentless expansion of commerce[8]. By the mid 18th century the situation in the Pool of London was unbearable. Congestion caused long delays and innumerable problems. Long queues and waiting times (up to three months to unload) exposed the goods to weather and pillage. Moreover, the ships that were moored in the pool suffered damages due to the lack of space between them. All these factors were compromising the feasibility of the port, as the cost of unloading was too high. By the 1760s the merchants had put a formal request for the enlargement of the legal quays, without success[9]. By 1797, over 10,000 coasters and overseas vessels were arriving at London annually, 3,400 lighters that carried goods to and from ships added further problems[10]. Contemporary accounts describe an scenario where the number of ships almost doubled the capacity of the Pool[11], they moored wherever they could find space, just leaving a minimum navigation channel in a river that was more and more polluted.

7 Al Naib, 1990
8 Barker, 1986
9 Ibid
10 Ibid
11 Ross & Clarck, p.139

The impediments to solve these problems were neither technical nor physical. In fact, there was plenty of space downstream, where new docks could be located. Some basins already existed in Blackwall (1660) or Howland Dock (1696), although they were used for maintenance and repairing labours, rather than cargo handling[12]. The main obstacle that prevented the development of new quays came from the City. The City's Corporation understood the port as a mere equity, ignoring the changing needs of such facility. They were reluctant to send such important activity away from their direct control. Smugglers were also contrary to the idea of new legal quays as that would put them out of business. By the 1790s, the West India Company, which calculated a loss between 250,000 and 500,000 pounds a year due to pillage, requested permission for the construction of new docks in the Isle of Dogs, an isolated marshland in a pronounced meander a couple miles to the east of the City. A counter proposal, presented by the North American and European merchants, was based on the demolition of several blocks at Wapping (closer to the City) to build a dock and the opening of a shortcut channel through the Isle of Dogs. After long discussions, both proposals were approved, but each one was financed by the corresponding company. In 1799 the West India Dock Act, which provisioned the construction on the Isle of Dogs, was enacted. In 1800, the London Dock Act would follow. Each company monopolized the trade of certain products and the use of the new docks, which contained the new legal quays and associated warehouses. Ship basins were completely enclosed by massive brick walls and had their own police force[13]. They formed isolated

12 London Dockland Study Team, 1973
13 Meyer, 1999

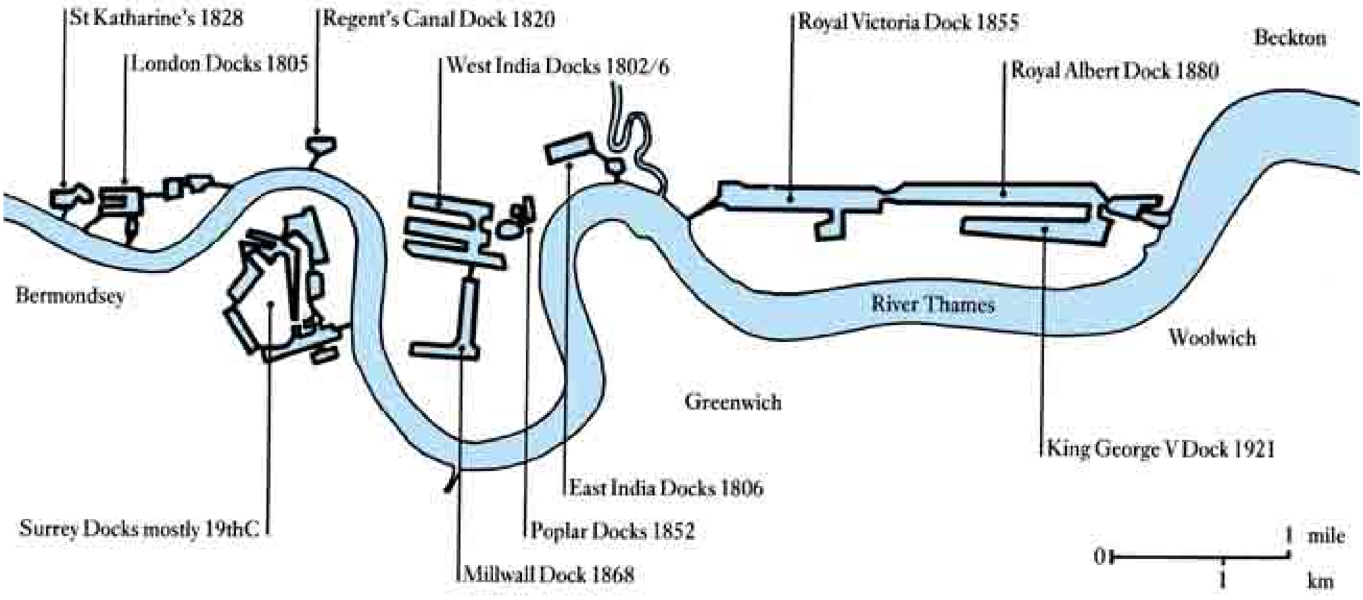


Fig.8-3 Chronology of London Docklands (after Barker, 1986)

enclaves, completely detached from the urban fabric that was advancing from the City eastwards to accommodate the workforce of the new docks. The effect of the new basins was immediate. They provided protection and more efficient means of cargo handling. The success and profitability generated by both docks encouraged new ventures. The next one to follow was the powerful East India Company, which opened their commercial docks in Blackwall in 1806, close to their former maintenance basin. Unlike the previous cases, this new dock lacked any warehouses and the goods were transported to a fortified warehouse in the City (Cutler Street). In this initial period, there were three main companies dominating the north bank of the Thames, each with their own dock (figs. 8-3, 8-4):

- The **West India Dock**, which was opened in 1802 (Import) and enlarged in 1806 (Export). They monopolized trade of all products from West India, except tobacco.
- The **London Dock** opened in 1805. A channel in the Isle of Dogs was built at the same time to reduce journey time avoiding the large meander. The company was granted the monopoly to handle tobacco, wine, rice, brandy and other goods from all parts of the world no covered by the rival's agreement[14]
- The **East India Dock**, promoted by the East India Company, was opened in 1806. The Company had had the monopoly of trade with the East Indias since Queen Elizabeth granted it in 1600. In 1813, it only retained the monopoly for China and tea trade. In the 17th century it had the largest ship reparation dock in the Thames at Blackwall Yard, which expanded at Brunswick (1789), Rotherhithe and Howland (1703)[15]

Other initiatives were underway in the south side of the Thames, but they took little part in the battles between dock companies in the north bank. The road communication was difficult as the nearest crossing point was London Bridge. The first dock development in Surrey docks were more oriented towards military purposes. Henry VII had established a royal shipyard at Deptford and Woolwich in the 16th century to serve the royal navy. When promoters devised a plan for a grand canal from Rotherhithe to Kingston, they were considering the Admiralty as potential investors. However those plans did not fully succeed. In 1807 the Commercial Dock Company was formed to develop the Greenland Dock (formerly Howland Great Wet Dock). Two further companies emerged in 1809in the south bank: the East Surrey Dock Company and the Baltic Dock Company[16].

The monopoly of the dock companies was granted for a period of 21 years. The end of monopoly brought about a period of intense activity. Companies and consortiums established by influential merchants of the City started to invest in new docks, which were seen as a good opportunity for speculation. One of the first initiatives to react to the expiration of monopoly was promoted by City merchants

14 Greeves, 1980

15 London Dockland Study Team, 1973

16 Ibid

Fig.8-4 Georgian Docks in the 19th century. Clockwise: West India Docks, engraving by William Daniell, 1802. London Docks, engraving by William Daniell, 1808) East India Docks, author unknown. Source: Museum of London

to develop a site between the Tower and London Dock, in what would be known as Saint Katharine's Dock (fig.8-5). It was a bold and ambitious plan since it implied the clearance of 1,500 houses and religious buildings in a very expensive site. The Dock opened in 1828 but it was never viable as the design, made by the renowned engineer Thomas Telford, was already outdated. The newer and larger ships could not use the facility[17]. The proliferation of new docks would eventually turn out in oversupply of quay area that caused a reduction in the companies' profits. Docks were not only competing among them but also against riverfront traffic. Despite the increase in the overall number of ships, many of them were coasters, which did not require port facilities. In 1835, only 25% of the goods moved in the port would pass through the docks[18]. The evolution of the ship was an additional problem. From the 1850s, companies were pressured with larger and larger ships due to economies of scale, the larger the ship the cheaper the expenses[19]. Georgian docks had been designed for wooden sailing ships, which for structural reason, seldom exceeded 1,000 tonnes gross, whereas iron steamships could easily reach 8,000 tonnes[20]. The East India Company was most affected by the evolution of ships. Their dock at Blackwall had been built with little foresight and the lock gates were too narrow and difficult to adapt for larger ships. In 1833, the East India Company ceased trading, after 233 years of dominion in India and China commerce. Some of its facilities, including the dock, were acquired by the West India Dock Company, which saw this expansion as a way to become more competitive in an increasingly combative market[21].

Larger docks were required to adapt to the new ships. Victorian docks responded to the new needs, incorporating hydraulic machinery for the opening of the lock gates and large basins. The first Dock of the new period was the Victoria Dock, completed in 1858, and considered the best dock in the World[22]. The new quays had a great impact in the West India Dock as it took most of the new steam traffic. Nevertheless, the successful operation of the Victoria Dock was counteracted by a poor financial management. An economic crisis forced

17 Greeves, 1980
18 Barker, 1986 p. 17
19 Pearsall, 1986

20 Al Naib, 1991
21 Some authors argue that West and East India companies merged. However, most literature refer to West India Dock when describing events from mid 19th century
22 Greeves, 1980

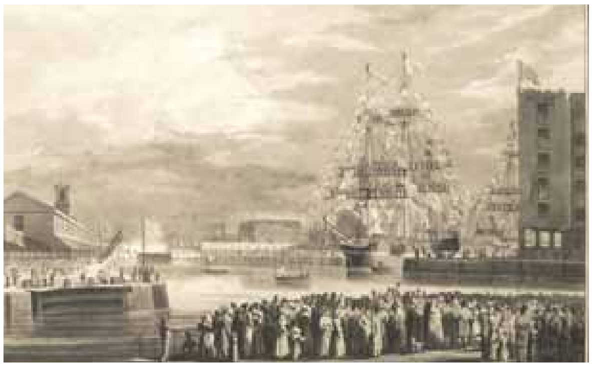


Fig.8-5 St Katharine's Dock. Left: Model at the Museum of Docklands. Right: The opening day on 1828, engraving by Edward Duncan,1829 (Museum of Docklands)

the majority of shareholders to sell the dock to the London and St. Katharine Dock Company around 1865, which had merged one year earlier[23]. The now prevailing companies, West India Dock and London Dock (merged with St Katharine and Victoria Docks) started a frenetic race to increase and update their Dock capacity. A third company had emerged in the middle of this battle, right at the doorstep of the West India Dock to build the Millwall Dock, an L-shaped dock at the Isle of Dogs. This enterprise was however unsuccessful as the low rates to attract ships never became profitable. The company was eventually absorbed by the West India Dock, but the low rates policy had harmed both corporations very badly. The merged company decided to expand the south quay in the Isle of Dogs to overcome the situation. Few years later, London Dock Company embarked an ambitious project to join Victoria Dock with the Thames at Gallions Reach by a new dock, the Albert Dock scheme, which was completed in 1880.

Fig.8-6 Royal Victoria, albert and King George V Docks around 1960 (Naib, 1990)

The London Dock Company was now in possession of the finest dock in the world. It was something that their bitter rivals could not stand. The most rational solution, given the economic problems caused by relentless competition, aggressive rate policies and increasing debt, would have been the amalgamation of the companies. However, instead of that, the chairman of the West India Company embarked in a new bold enterprise: the construction of new dock at Tilbury, 26 miles downstream. The intention was clearly to divert big ships to the new facility, before they reached the brand Royal Docks (Victoria and Albert). The railway development (which at the time was at a similar explosion around the country) would facilitate the communication, both with London and the eastern counties[24]. A new battle was settled, everything but fair competition was put in place to seduce trading companies: bribe, unfeasibly low rates and lobbying. The battle ended up with the eventual liquidation of the West India Company, only two years after the completion of Tilbury Dock (1886). In 1889, the two rivals reached a working agreement to form an amalgamation known as the London and India Dock Joint Committee[25]. The battle for the control of London Docks, driven from private interests, had come to an end. In the way it had transformed the riverscape of east London from a marshland into a sequence of isolated

23 Al Naib, 1991

24 Greeves, 1980 p. 13

25 Ibid

industrial enclaves. The haphazard expansion had led to short sighted dock designs, without access to railways, small gates and inefficient warehouses. The relation with the city was residual and the East End would develop in a monofunctional zone characterized by the presence of the docks and manufacturing companies. The Isle of Dogs, which has always been a peninsula, would become a real island, a world away from London.

8.1.2. Rise and decay of the Port of London (Authority)

The lack of strategic vision of the private Dock companies in the 19th century led to collapse and bankruptcy. The financial capacity of the merged corporation was very limited. They could not afford the major improvements that were necessary to update the port of the greatest Empire. It became a matter of national interest, as proved by King Edward VII's speech at the opening of the Parliamentary Session of 1903, in which he included a bill for the establishment of a new Port of London Authority (PLA)[26]. In 1908 the Port of London Act was enacted and the PLA was set up. The London and India Dock Joint Committee was nationalized by a compensation agreement and the new public body acquired the freeholds of the five enclosed docks. For the first time, the Docklands would be developed with a plan, long term thinking and efficiency driven priorities. The first actions of the PLA addressed the most urgent issues, repair and improvements in the existing facilities and dredging the channel of the river, and two strategic decisions, the construction of a new Head Office and a new dock at the Royals. The King George V Dock was finally opened in 1921 and it meant the end of major dock building in London Docklands (fig. 8-6). After that, major investments concentrated in modernizing warehouses and the introduction of mechanical systems.

During the World War II, the port became a priority target of German air raids between 1940 and 1941. Almost 30% of the warehousing at London and Saint Katharine's Docks were lost[27]. East London local communities were strongly hit by the effect of the attacks. Many of the goods stored in the docks were inflammable (timber, rum...) which augmented the devastating power of the bombs. Chronicles described how the dense smoke made impractical to fight the fire in the warehouses, which could burn for several days. Once the war was over, repair works took a slow pace. The PLA was aware that the introduction of modern mechanized system would be required to shorten the ship's berthing times and thus reduce costs. Many of the surviving old warehouses were knocked down to introduce the new technologies. The efforts of the PLA were being fruitful and trade reached new peaks (over 65 million tonnes of cargo a year) by the early 1960s[28]. However, a new revolution in shipping and cargo technologies had far reaching consequences in the future development of the area.

26 Ibid
27 Ross & Clarck, p.263
28 Al Naib, 1991

In the mid 1960s, the standard dimensions, ratings and specifications of containers were universally agreed[29]. This event brought massive changes as containers enabled traders to load standard steel boxes, anytime, anywhere, using off-wharf labour. The work in the docks was reduced and it could be easily automatized, which meant that large number of dockers and stevedores became redundant. With the new systems, only 3,000 workers, out of the 30,000 that were employed in the Port, were required to handle about 50 million tonnes of goods a year. Containers had been also devised to optimize seaborne and land transport coordination. Modern ports required a broad logistic area and an excellent connection with railway lines to enable this intermodal exchange. In Docklands, only the Royal Docks could realistically adapt to those needs. The poor communications and shortage of space was an important burden in the docks that were closer to the City. Although container cranes and berths were provided, the innermost docks started to lose trade and be shut down by the PLA. The West India Docks was closed in 1967, St Katharine's in 1968, the London and Surrey Docks in 1969, West India and Millwall docks were shut down in 1970 and, finally, the Royal Docks closed in 1985. The PLA concentrated efforts in the only economically viable premise at Tilbury, which benefited from its excentric position and the ease for expansion to create new container terminals. In Docklands, the PLA filled the old Surrey and East India Docks. The idea was to develop those to make a profit. However, in the middle of a global economic recession, the only market was for low grade industry, scrap merchants and haulage depots that undermined, even more, an already degraded environment[30].

Fig.8-7 Decaying industrial estates at the Royal Docks

29 McLean, 2012
30 Edwards,1992

The future of East London, in general, and Docklands in particular was marked by a mixture of fatalism, rage and uncertainty. The Port was the bread and butter for thousands of families in the area. Not only dockers but also workers of complementary industries and services were directly or indirectly related to Port activities. One hundred years ago, these communities had stood up against precarious labour conditions and had set the foundation for unionism and the labour party. This time, it was not only a social problem but also economic and environmental issue that would be tackled from planning. Urban regeneration was an emerging field that found one of the biggest challenges in London Docklands, a vast area in dereliction, unattractive for developers, filled with contaminated soil, struck by unemployment and poorly connected. Diverse studies and plans would overlap in the next thirty years to transform the old Docks into the new economic node of London.

8.2 Regeneration of London Docklands

8.2.1. Docklands as example of urban containment

The migration from the city centre to areas with a more rural character had become the dominating trend since the World War II. The decentralization promoted by Abercrombie's advisory plans had been realized, even further than expected. The Shout East Study[31] had foreseen an increase about 360 thousand families moving to the suburbs between 1961 and 1981 as a result of the limited additional housing capacity in Central London. In this study, densification policies were being proposed in several areas to counteract the flow beyond the green belt:

- Dense central neighborhoods, many of which were slums listed for reconstruction. There was little scope for further densification.
- Low density suburbs, built during the interwar period. There was more space but houses were relatively recent.
- Victorian and Edwardian semidetached housing were proposed as potential areas for reconstruction densification. Many of them could be subdivided in flats.
- Derelict land that belonged to institutions enabled unitary interventions and a net housing increase.

The estimated additional housing capacity in each on these areas of Central London was summarized in the following table:

Table 8-1 Additional Housing Capacity in Central London 1961-1981[32]

	Additional dwellings
Vacant Land	30,000
Low density zones	90,000
Subdivision of houses	45,000
Reconstruction in general	25,000
Total	190,000

The housing needs for the period was estimated in 550,000 new dwellings, which gave the number of 360 thousand homes to be built beyond the metropolitan area. The number of commuters would rise beyond one million.

Urban containment was now the target and the regeneration of Docklands was one of the earliest experiments to reverse urban sprawl. If the transformation was successful to retain both jobs and population within the existing city, less pressure would be exerted on greenfield land. The transformation of London Docklands is a process of containment and densification in the inner city. What recent urban theories have so decidedly supported can be evaluated throughout this process. The clashes between colliding interests, diverging views, social unrest and alternative planning approaches that were generated during this experience will be deeply illustrated in following paragraphs. The analysis will be focused, but not limited, on the most active part of Docklands: the Isle of Dogs, where the most radical policies were implemented and local residents rose most fiercely against regeneration plans.

8.2.2. Social and planning context

The aftermath of the WWII was a period of intense building activity. The German raids had destroyed one third of the dwellings[33] around the Port of London area. There was an urgent need for massive housing construction, which had to be inexpensive and quickly done. The problem was also seen as an opportunity to apply modern planning principles, aiming to improve the hygienic conditions of the Victorian urban fabric. Slum clearance programmes were implemented to replace the old terraces by council blocks[34]. However, the tower block typology that was adopted had a bad reputation in London, due to its strong association with poor quality and deprivation. The partial collapse of Roman Point in 1968 in Newham[35] and the fact that re-housing programmes caused the dissolution of well established communities and family links did not help to improve the perception of modern planning developments.

The communities that had been formed around Docklands were mainly related to the port and the industrial

31 Ministry of Housing and Local Government, 1964

32 Ibid

33 Brownill, 1990 p.17

34 Housing managed by the local authorities and rented to low income families

35 Newham Story, 2009

Fig.8-8 Isle of Dogs, the West India Dock at the background c. 1930 (Island History Trust)

development that started in the 19th century. Working class prevailed in a rather horizontal social structure. The docks acted as physical and psychological barriers that enhanced the introspection and isolation of the neighborhoods in the area. This was particularly strong in the Isle of Dogs, where the settlements had a village character and their inhabitants saw themselves not as belonging to Docklands or the Isle of Dogs but as part of smaller communities, such as Cubitt Town or Millwall[36]. The local identity was very strong, which reinforced the reluctance against newcomers, social blocks and relocation programmes. The working conditions had improved greatly since the 19th century, mainly because of the active campaigns and the power acquired by the labour unions. However, casual work was still operating until the 1960s and the area was among the most deprived zones, not only in London but in the whole Britain. In addition, heavy industries had left serious environmental damage as a legacy, not least chemical waste and contaminated soils, which posed serious risks for the health of local residents. The historical working and living conditions may have induced, according to Foster, a "sense of struggle and a negativity that remained a hallmark of established Islanders even in the 1990s"[37]. She reported different testimonies on how the new residents of the 1990s perceived the locals of the Isle of Dogs:

36 Foster, 1999
37 Ibid

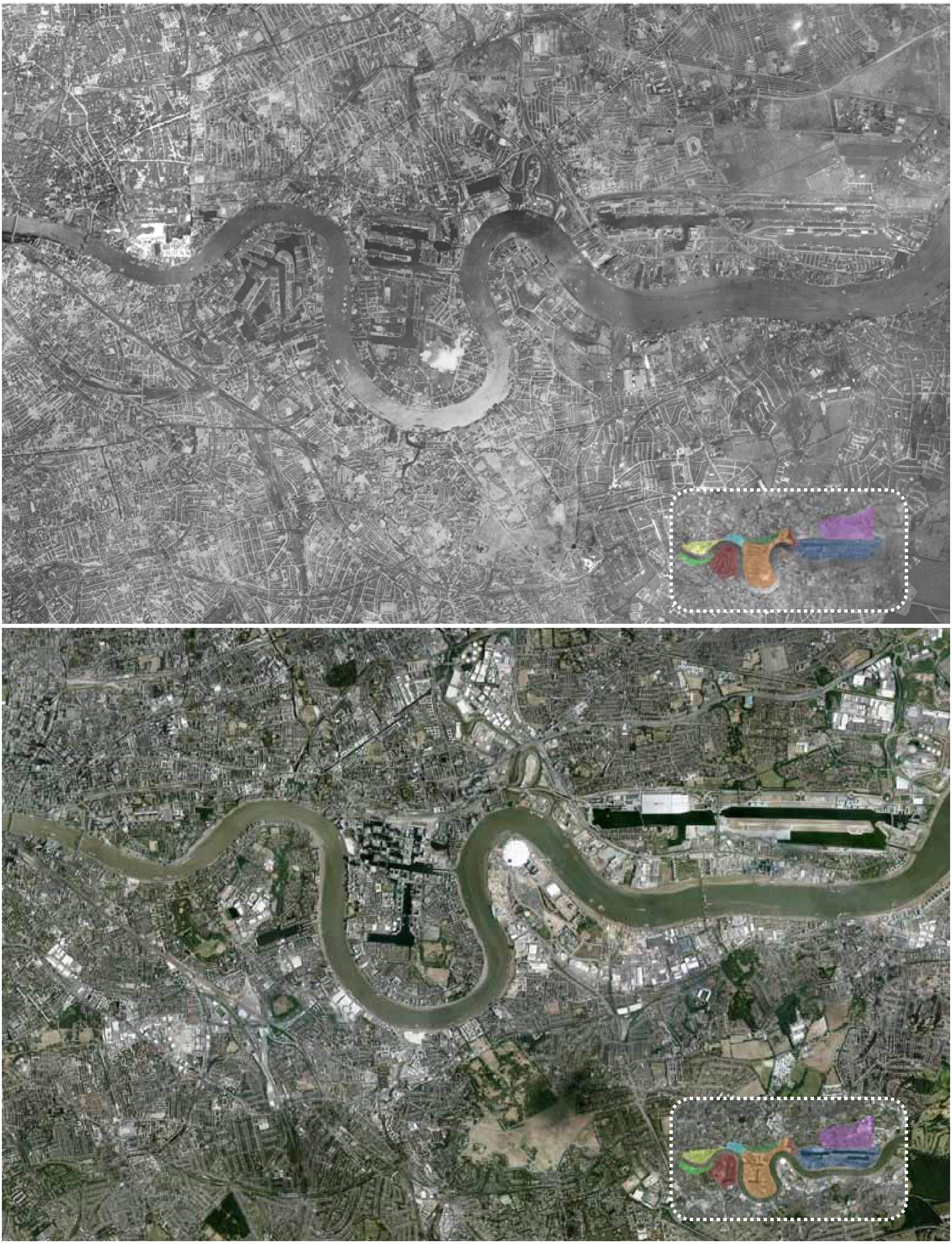
"There's always a negative aspect to things...I couldn´t believe how devastatingly suspicious, how naturally the instinct of Island people is to see the worst and to see a threat in everything. Now that is desperately sad and I can only assume that that comes from having been at the lower end where horrid things have always happened and big people up there have always taken decisions which affected their lives which they've been powerless (to influence) and are always in a defense position, to have to react and never initiate."[38]

Despite a brief period of prosperity after the WWII, the activity of the Port had been steadily decaying since the 1930s. In the 1970s the situation was unsustainable and the gradual closure of the docks caused a massive job loss in the area. From 25,000 dockers in 1967, there were only 4,000 left in 1981[39]. It has been estimated than over 75,000 jobs were axed in East London during the 1970s[40]. The labour crisis was followed by an emigratory wave. The dark perspectives led to a loss of population and most of the people that stayed in Docklands were council tenants (80% in 1981[41]). A great proportion of them were living on benefits.

Fig.8-9 The massive walls that closed the Docks increased the insular feeling of the Isle of Dogs (Naib, 1986)

The need for some kind of action was clear at every administrative level. However, the two main parties had converging views, which together with the complex competences overlapping on the zone, caused considerable delays and limited the scope of initial plans. Conservatives relied on private agents to introduce energy and momentum whereas the Labour party defended a traditional approach, led by public initiative to ensure that fair attention was paid to the needs of local residents. To some extent, the regeneration of London Docklands can be explained as a continuous struggle between the private and the public, as well as national and local interests.

38 Ibid, p.15
39 Brownill, 1990 p.18
40 Foster, 1999 p.37
41 Hardy, 1983



St Katharine's Limehouse Poplar Isle of Dogs Canning Town Beckton Royal Docks Surrey Docks Rotherhithe

Fig.8-10 London Docklands in 1941 (top) and 2012 (bottom). The main areas are coloured in the inset (source: Cities Revealed © The GeoInformation Group 2013 and GoogleEarth © 2013 Bluesky)

8.2.3 The London Dockland Study Team Report

In 1971, after the closure of Saint Katharine's Dock and following the concerns about the job losses and the need for coordinated action, the Conservative Secretary of the Environment, Peter Walker, and the Greater London Council commissioned a comprehensive study on the Thames-side area between London Docks and Barking Creek[42]. The study should set the basis for the future redevelopment of the zone. The earlier proposals of the Greater London Development Plan had failed to detect the imminent closure of the Docks and did not provide any alternative. On the other hand, the project for the redevelopment of Saint Katharine's Dock, which transformed the basin into a marina, with a five star hotel, luxurious flats and stores, was an early glimpse of what the future of Docklands could look like. The London Dockland Study Team, an had-hoc consultancy team that was set up for the study[43], embraced a regeneration based on services and high end residential, or as Peter Walker put it: "a West End in the East End"[44]. The study area covered around 2,250 ha, excluding the rivers (Thames and Lee) and it stretched nearly 12 km from Saint Katharine's Dock eastwards. This delimitation can be hardly explained from any administrative, economic or traffic pattern. The main criteria were the proximity to the Docks and the inclusion of industrial estates (Gas Board and Beckton Sewage Works) that can afford a large amount of brownfield land for development (fig. 8-11).

Major land ownerships accounted for some 80% of the area. The largest part corresponded to the Port of London Authority (825ha), followed by the GLC (340ha) and the British Gas Corporation (279ha)[45]. Most of the industrial estates were readily available for development as changes in technology had caused the obsolescence of many their premises. The overwhelming corporative ownership of the land represented an opportunity to implement large scale projects but it was, at the same time, an excuse to bypass consultation with the local communities, which resulted in fierce opposition and, eventually, the failure of the plan.

The study contains a comprehensive analysis on the history and evolution of the Docks. The main problems and demands of the time were identified (basically regarding housing and employment, but also shopping, recreation and the social mix) and up to 18 different proposals to redevelop the area were put forward. A bespoke multi-criteria evaluation system was created to compare and assess the different alternatives. Supposedly objective, the system selected 6 out of the 18 proposals. After further scrutiny, the plan dubbed as "City New Town" was identified as the most favourable. It was a commercial plan, based on private interests, characterized by large shopping centres, office buildings and the complete lack of consideration towards local needs. Only 1,000 jobs in manufacturing were considered, whereas 60,000 new jobs in services and offices would be allocated, according to the predictions of the study.

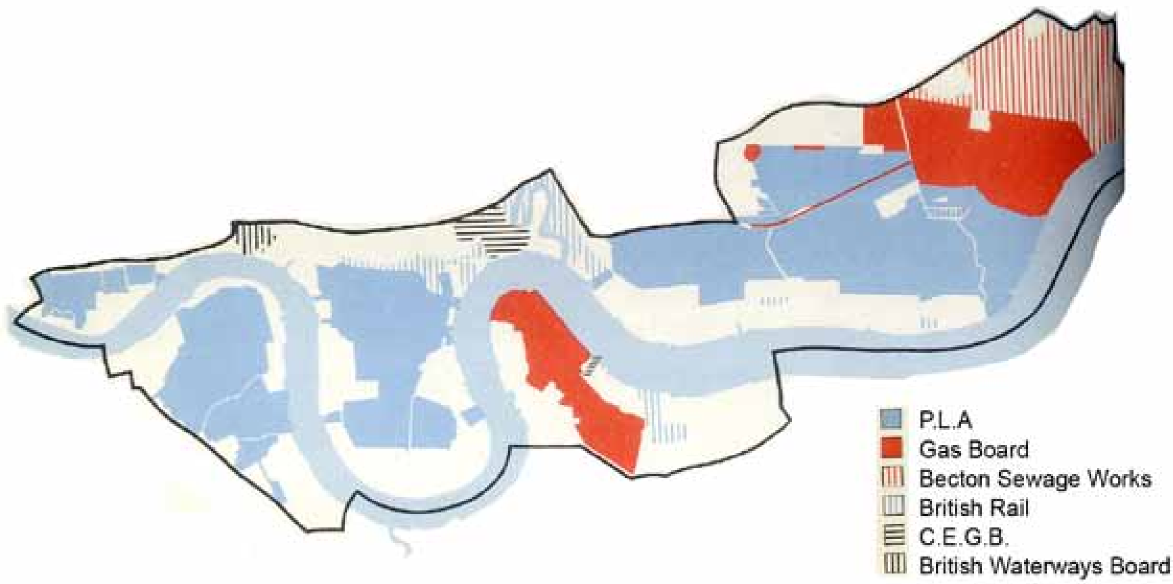


Fig.8-11 Delimitation of the London Dockland Study Team's Study area and patterns of major Land ownerships (after London Docklands Study Team, 1973)

42 London Docklands Study Team, 1973

43 The London Docklands Study Team was established by Travers Morgan & Partners as principal consultants. They hired external consultants and teamed with officers from the Greater London Council

44 Brownill, 1990

45 London Docklands Study Team, 1973

Fig.8-12 The study area was contained in five London boroughs (London Docklands Study Team, 1973)

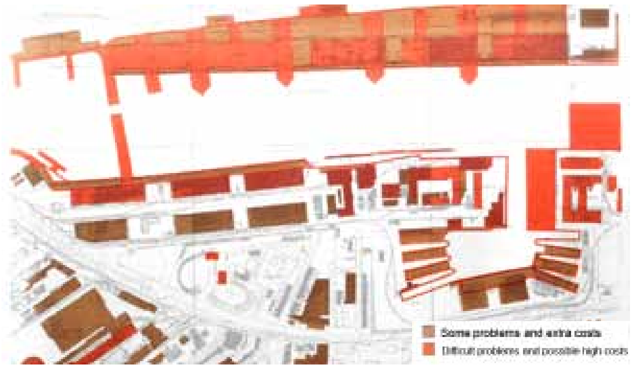


Fig.8-13 Possible site clearance problems identified at the Royal Docks by the LDST (London Docklands Study Team, 1973)

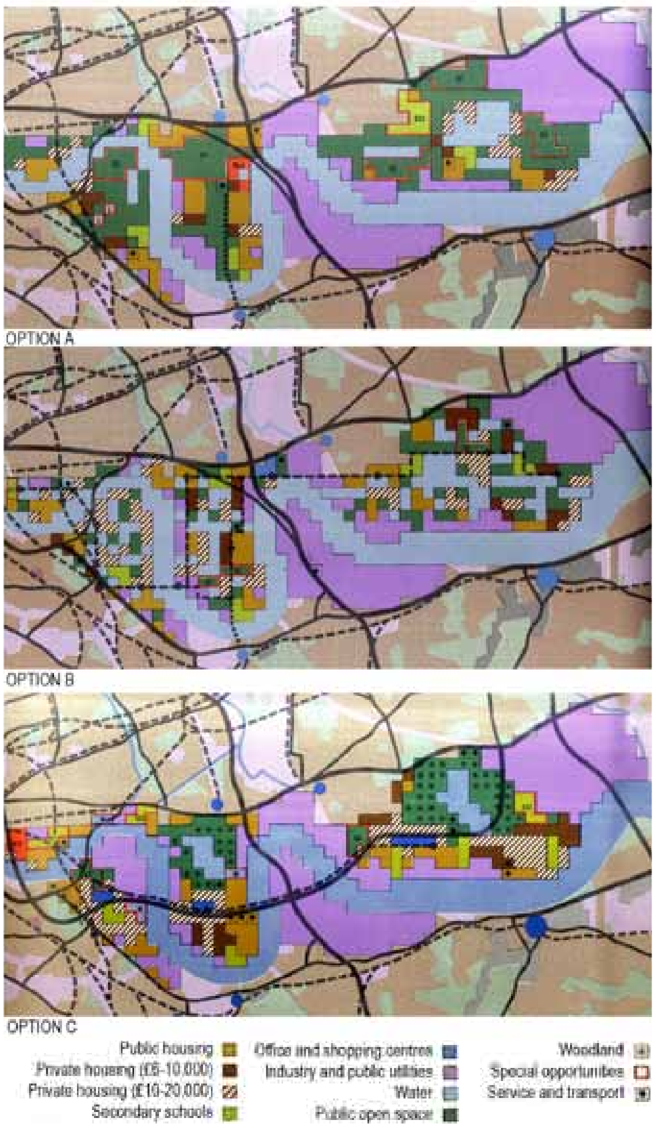


Fig.8-14 Diagrammatic representation of the plans. Each cell of the grid represents the prevailing use on 4ha squares. These three options have low resident population and large areas of open space (after London Docklands Study Team, 1973)

The report was received with hostility, not only by the boroughs but also by the residents. The study area spanned over five London boroughs, whose councils owned some 214 ha, most of it in housing estates. The local authorities were reluctant on any imposition that could undermine their planning powers or usurp their access to capital gains derived from planning. Neither the councils nor the boroughs were consulted at any point and information was only provided afterwards. This was at a time were community planning was emerging. Numerous social action groups were formed to combat elitist approaches to planning, in which top down decisions ignored local needs and demands. The Travers Morgan study (Aka London Dockland Study Team) was a prime example of that. Luxury flats, marinas, white collar jobs and golf courses were not the priorities of a community struck by unemployment, with limited skills and little resources. It triggered a number of these action groups in the area (Joint Dockland Action Group, North Southwark Community Development Project...[46]) that voiced local demands, which fundamentally consisted on maintaining and reinforcing the industrial activity, increasing the social housing stock, and the investment of planning gains in the local community.

When the Labour party gained the GLC in 1973 and the central government in 1974, they dismissed the plan altogether and created a new planning entity to prepare a different regeneration strategy: the Docklands JointsCommittee (DJC)

46 Brownill, 1990

8.2.4 London Docklands Strategic Plan

The failure of the London Dockland Study Team (LDST) report may have been caused by a number of factors: political battles, the economic and property crisis of the mid seventies or the inability to engage the local community were named by experts as likely reasons. The new labour governments were aware of that and, consequently, the Docklands Joint Committee (DJC) had a stronger social focus. The local community was represented by members of the five boroughs included in the area defined in the LDST report plus two members from the Docklands Forum and the Joint Dockland Action Group. The purpose of the Committee was to create an strategic plan that coordinated the future development of the area, but with a stronger social approach. The resulting document was presented in 1976 as the London Docklands Strategic Plan (LDSP). Whose major aims were declared as follows:

"To use the opportunity provided by large areas of London Docklands becoming available for development to redress the housing, social, environmental, employment, economic and communications deficiencies of the Docklands area and the parent Boroughs and thereby to provide the freedom for similar improvements throughout East and Inner London"[47]

The main lines of the plan addressed housing and employment, reflecting the local concerns but somehow it neglected the broader economic evidences. Twenty three thousand new dwellings were to be built, most of them for public low-rent housing, together with a provision of public facilities (schools, libraries, health care...). The closed Docks would be filled to build new industrial facilities and hence provide jobs that matched the skills of the local population. Despite the proximity to the City, the provision of office space was not seen as a priority. The plan took the naive assumption that the docks that had not been closed at the time would remain open. That prediction would be used to criticize the plan as being parochial and short-sighted[48]. The hopes of the plan could not stand against the reality. There was a large oversupply of industrial space around London and housing authorities, as every public agency in the country, were cutting their budgets due to the austerity nation-wide policies. Therefore, the economic strategy had to rely on the provision of extra funds (£1,138 million in four years) from a Government that was being forced to apply massive cuts across departments and a similar investment from private investors, which had not been consulted at any point. In practice, once the boroughs were aware of that lack of funding, they would accept any proposals against the spirit of the LDSP. They simply wanted something to happen, even if it implied commercial developments and luxury flats.

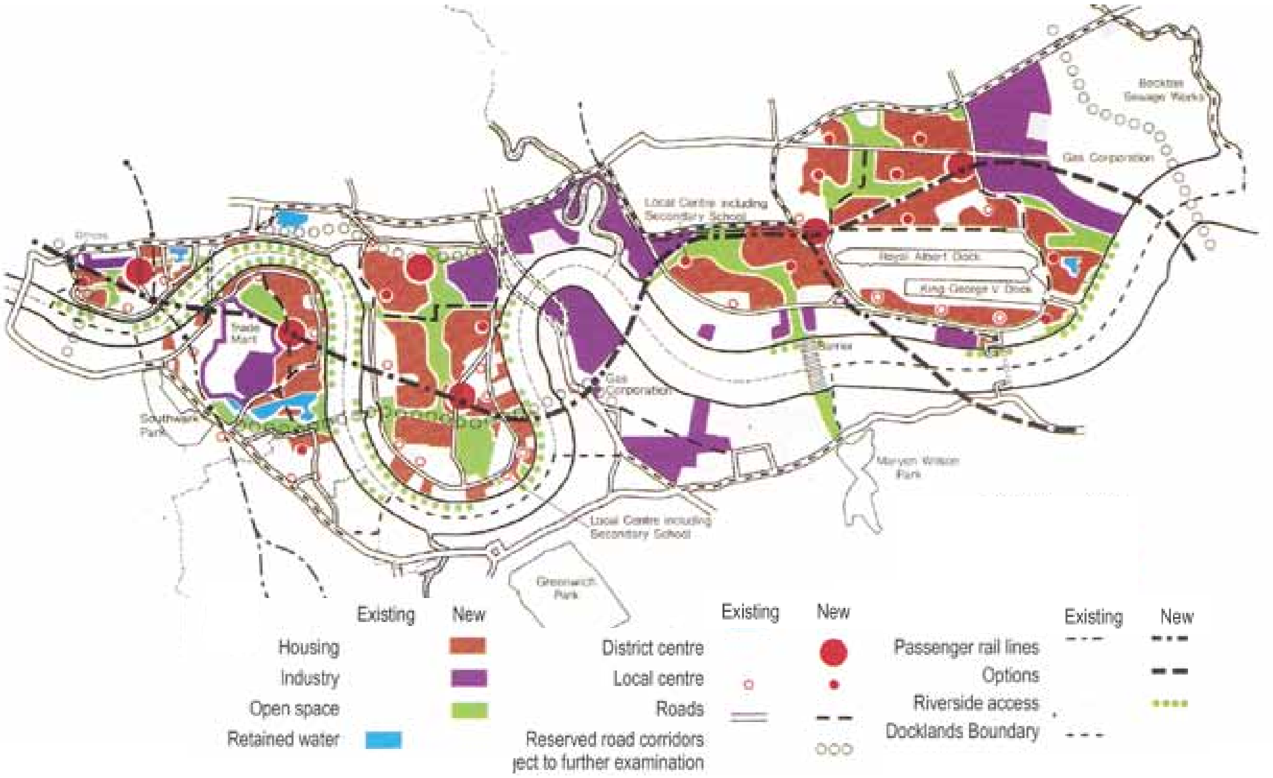


Fig.8-15 Land use map as proposed by the LDSP on its final stage. This map intended to predict land uses at 1997 (Docklands Joint Committee,1976)

47 Docklands Joint Committee, 1976 p. 2

48 Hall, 1988 p.352

The implementation of the LDSP was short-lived. During the lengthy consultation process the social and economic scenario had worsened considerably. The industries of the zone accelerated their decline and thousands of jobs were being destroyed every year. The DJC and the LDSP showed a poor performance since they had been unable to meet any of their objectives. Only 25% of dwellings, 30% of industrial space and 8% of jobs respect to the initial targets had been fulfilled[49]. According to Meyer, the main success of the DJC had been the agreement with media companies (e.g. Daily Telegraph) and chain stores (ASDA Superstores) to locate their main warehouses at Docklands[50]. In contrast, people were leaving the area, looking for opportunities somewhere else.

Another shift in the political colour at the GLC first (1977) and Downing Street later (1979) put an official end to the implementation of the LDSP, as well as to the DJC. The numerous analyses on the failure of this plan present several common features:

- The plan did not offer a realistic alternative to the causes behind the closure of obsolete industries. It simply tried to avoid change.
- In a recession economy, conventional land use planning is not operative since nothing happens unless there is a pressure for development. The plan itself is not enough to activate a zone, further incentives are needed.
- The public interest is not just the local interest. Large infrastructures cannot be devised and justified from a local perspective[51].
- Planning decisions need a consensus between the main political forces or they need to be independent. Otherwise, changes in the administration may lead to a constant succession of proposals and counterproposals, without a chance for their actual implementation.

8.2.5. The radical experiment: LDDC

The conservative party that regained government in 1979 had a different attitude than the previous Tory administration. The experiences of the seventies had demonstrated that conventional strategic planning had been unable to solve the inner city problem. This was used to reprobate "social plans", whose excessive restrictions were seen as deterrence for private investment. The ultraliberal capitalist government was to base their approach to Docklands in two basic principles:

- Roll back of public involvement to pave the way to a market-led approach
- Gains for locals would only come as trickle down benefits from successful developments[52]

A more energetic response was needed to what was seen as a matter of national interest. The inspiration to shape the bureaucratic framework was the postwar New Town Act which, as Peter Hall ironically pointed out, had been initially devised by a radical Labour government and detested by Tory voters[53] because it bypassed their local councils. The Local Government Planning and Land Act of 1980 (LGPLA) defined two new types of planning figures that synthesized the intentions of the government: The Urban Development Corporations (UDC) and the Enterprise Zones (EZ)

The Urban Development Corporations were agencies created had hoc by the Department of the Environment to secure the regeneration of the area they were ascribed to. They followed the model of the New Towns, with even greater powers. They seized planning control within their circumscription, superseding the local authorities. Therefore they could grant planning permissions without consultation or right to appeal whatsoever. The 1980 Act defines the object of the UDCs as:

"*Bringing land and buildings to effective use, encouraging the development of existing and new industry and commerce, creating an attractive environment and ensuring that housing and social facilities are available to encourage people to live and work in the area*"[54]

For the purpose of this object, the UDCs were provided with the following powers:

- Acquire, hold, manage, reclaim and dispose of land and other property
- Carry out building and other operations;
- Seek to ensure the provision of water, electricity, gas, sewerage and other services;
- Carry on any business or undertaking for the purposes of the object; and
- Generally do anything necessary or expedient for the purposes of the object or for purposes incidental to those purposes[55].

The Enterprise Zones were the key instruments in which the experiment relied. The original concept has been attributed to Peter Hall, as he accounts in Cities of Tomorrow[56]. Hall had made a call for unorthodox remedies to address the inner city problem. He mentioned a final alternative that consisted on the designation of small selected areas of the city where control over entrepreneurship and capital would be kept to a minimum. The system would be based on "fairly shameless free enterprise" and almost inexistent bureaucracy[57]. It basically meant less red tape as a lure for investors to leave them do their thing. That was, nevertheless, expressed as a possible

49 Brownill, 1990
50 Meyer, 1999 p.89
51 Carmona, 2009
52 Coupland, 1992
53 Hall, 1988 p.352
54 LGPLA , 1980 art. 135
55 Ibid. art. 136
56 Hall, 1988 p.356
57 Ibid

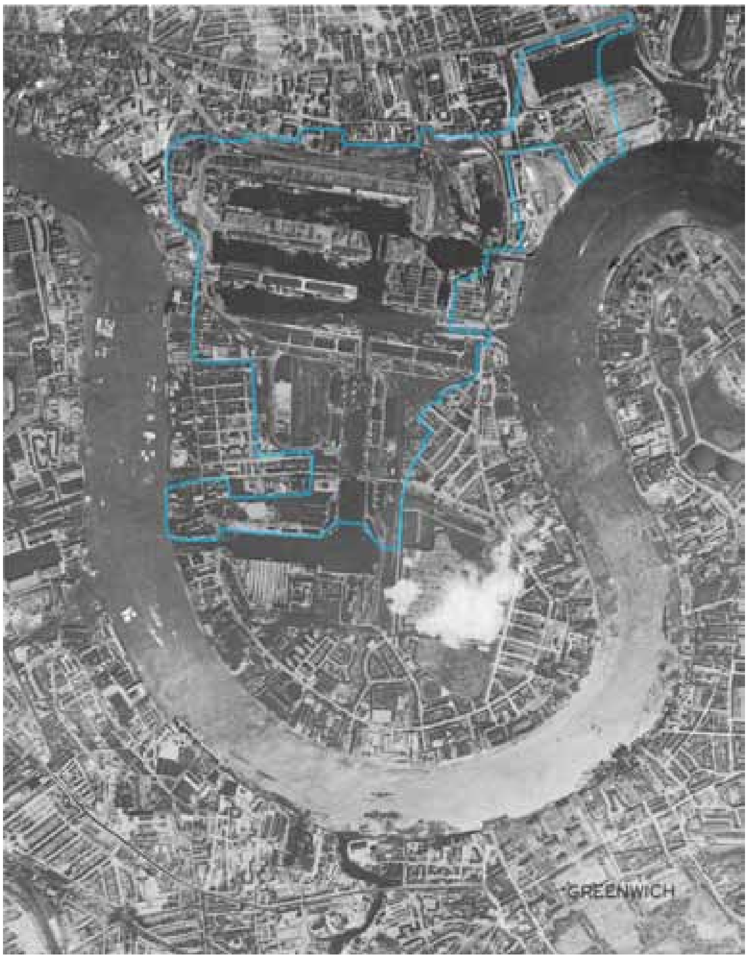


Fig.8-16 The Isle of Dogs in 1941 (Cities Revealed © The GeoInformation Group 2013). In blue, the Enterprise Zone

Fig.8-17 The Isle of Dogs in 2012 (GoogleEarth © 2013 Bluesky) In blue, the Enterprise Zone

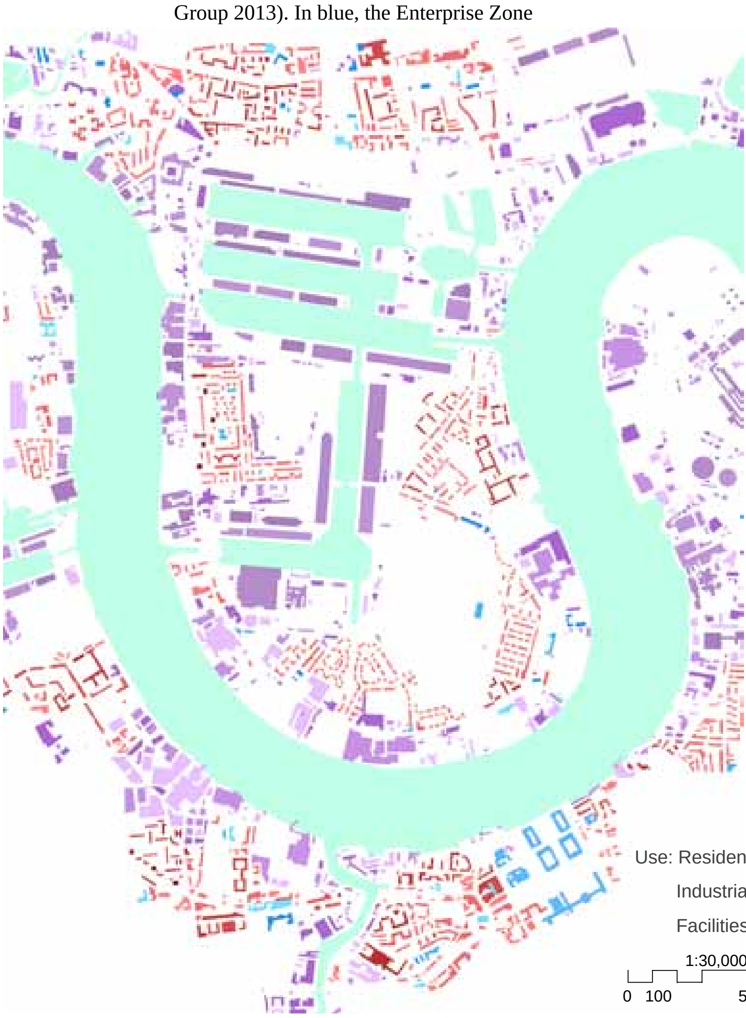


Fig.8-18 Land use in the Isle of Dogs in 1981

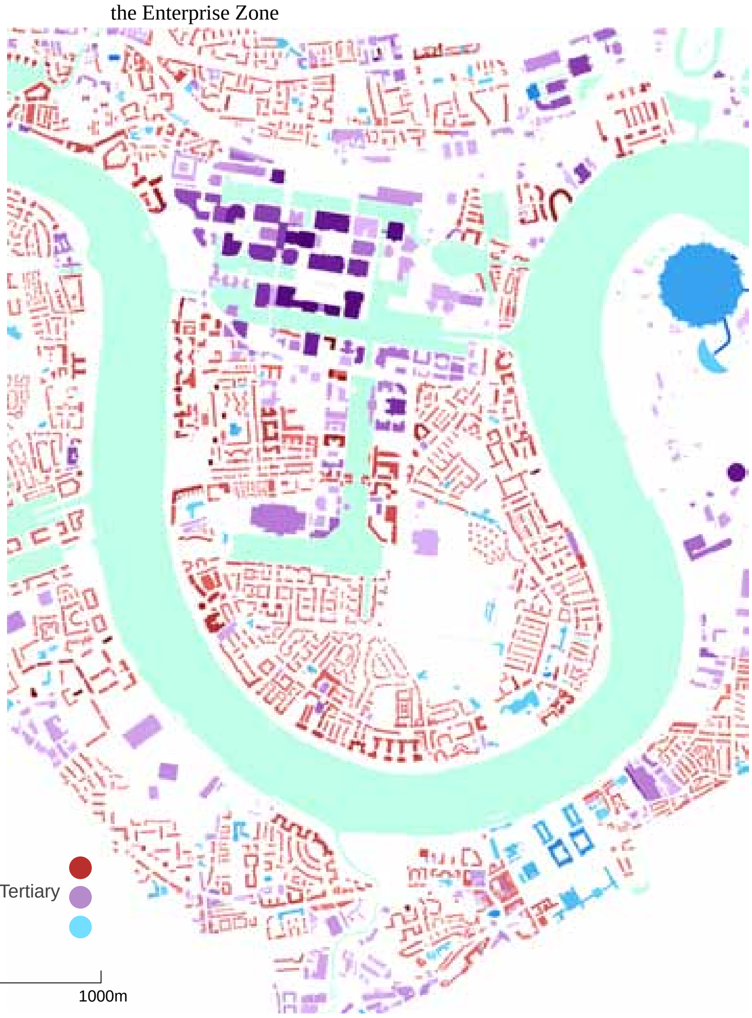


Fig.8-19 Land use in the Isle of Dogs in 2012

solution, a "last ditch[58]" not to be taken immediately. But the Government considered that, if all the conventional measures, which had been applied in the seventies, had failed, it was time for unconventional solutions. The provision for the Enterprise Zones was introduced. In the official definition, they provided a number of benefits to developers, investors and occupiers of industrial and commercial properties, including:

- Exemption from development land tax
- Simplified planning procedures. With variations from one zone to another with cases where planning permission was not required
- Exemption on industrial training levies
- 100% tax allowances for investments in construction. The taxpayer subsidizes the constructions costs of any building[59]
- A ten year rate free "holiday". It is an exemption from business rates for the occupiers. The government pays the rates directly to the local authority, therefore the developer can charge higher rents
- Less control on building regulations[60]
- Minimum amount of government form-filling[61]

The Secretary of the Environment, Michael Heseltine had announced, with the LGPLA, the designation of two Urban Development Corporations, in London Docklands and Liverpool Merseyside respectively. The administrative jurisdiction of the London Docklands Development Corporation (LDDC) differed from the LDSP. It excluded Greenwich and Lewisham to incorporate Hays Wharf, St. Katharine's Dock and Beckton. The Enterprise Zone was located at the Isle of Dogs, around the former West India Docks. The new agency would be in charge of the regeneration of Docklands, not so much by means of studies and grand plans, but by triggering action, attracting investors and promoting the place as a haven for developers.

This new twist in the approach to inner city regeneration was contested. The main opposition came from the Greater London Council. The GLC was controlled, from 1981, by a new "hard" left led by Ken Livingstone ("Red" Ken), whose urban agenda was at the opposite extreme of the liberals. They had included a series of proposals for the Docklands in their electoral manifesto and, once in power, they supported community organizations to monitor the activities of the LDDC. The Conservative government had many reasons to wish the abolition of the GLC, as it was the main shadow to Tory's power after the general elections of 1983. They managed to pass the bill that declared its abolition in 1985, which came into effect in 1986. The most powerful opposition to the LDDC was out of business but community groups and labour controlled local councils would still present a fierce and active resistance to development forces.

Urban commentators tend to distinguish different periods in the life of the LDDC. A possible division could respond to changes in the direction of the corporation. The LDDC was managed by a board of 13 members. The board had to name an executive director, who was in charge of some 80 full-time employees plus external consultants for specific tasks. During the life of the LDDC there were four chairman and five executive directors. The former would ultimately dictate the approach taken in each period (see figure 8-21)

8.2.5.1. 1981-1984 Activation of a deprived area

The initial years of the LDDC were characterized by the campaigns to change the perception of the area. It was assumed that the first objectives should be the improvement of the image of Docklands and the introduction of mechanisms to attract investors. Both the appointed executive director, Reg Ward, and the chairman, Nigel Broackes, had expressed their scepticism about conventional planning. A plan was a constrain rather than an advantage. The previous decade had shown the inability of planning to regenerate a deprived area:

"My experience had led me to have a healthy disregard of conventional planning systems, because if you have an area with major problems, an area where nobody wants to go and where nobody's prepared to invest you can prepare all the plans that you like but nothing will happen (...) You had to say, this is not a problem area, it's one that's just brimming with opportunities, it's simply that people have not perceived them"[62]

At the beginning, the potential of the zone as commercial centre was not as clear as it is from today's perspective. The area was desolated. It was a landscape of dereliction and abandonment. It lacked basic services and proper transport connections. Its industrial past had left a legacy of contaminated soil and a depressing atmosphere. The main asset to counteract these burdens was the location. Docklands were at an arm's length to the financial centre of the country but it had remained as a world apart, due to the Docks, walls and the poor access.

The LDDC did not produce a plan, indeed they were only granted control powers and no planning competences. Instead, they elaborated annual corporative reports, in which the objectives for the year were summarized. Additionally, they prepared "policy statements" and "planning briefs", flexible frameworks that were used with marketing purposes rather than as strategic guidance. However, several basic principles were clear from the outset:

- The Docks should not be filled. They would be used a reminder of the past and to provide a distinctive character to the area. Cranes were purchased and installed in

58 Ibid
59 Coupland,1992
60 Brownill,1990 p.32
61 LDDC (1982) London's Enterprise Zone Designated. London Docklands Development Corporation Press Release

62 Reg Ward quoted in Foster, 1999 p.63

Millwall Dock to reinforce the naval atmosphere.

- There would be a programme to repair and restore historic buildings. Heritage was used as development lure[63], although it would be subdued to development opportunities. Generous funds were dedicated to churches and conservation areas. Conservation was implemented at building scale while urban structures were somehow neglected. A paradigmatic example was the impact on the Greenwich axis, which connected the observatory, Wren's Hospital and Hawksmoore Church at Limehouse[64].
- The improvement of accessibility was one the main priorities. New transport routes would include river, road and train connections between the City and Docklands.
- New urban services would be provided, including cutting edge telecommunications technology.
- All new housing would be private housing. That was understood by the LDDC as a critical aspect to achieve a balance in the community. There was an overwhelming majority of council homes (95%)[65] so that it was argued that a more even proportion would contribute to improve the perception of the place. The social revolts in Parisian suburbs were brought up as examples of problems arising in mono-class districts.

These principles were translated into specific instruments, used to remove the barriers that prevented development. The idea was to dedicate a modest amount of public funds to generate a larger private investment. An strategy that urban analysts have termed as "**leverage**" planning and that had been experimented in American cities such as Boston, Baltimore or New York[66]. Public money was mainly devoted to infrastructure provision and marketing, which could eventually change the perception of the zone and, subsequently, rise land values. As the investors were attracted by the perspective of profits as they would be interested in capital gains by the appreciation of land and the potential turnover from rentals. The regeneration became purely physical and broader aspects (social, environmental) were neglected. The strongest criticism to the LDDC was, precisely, about their complete lack of empathy with local residents, who felt they were being left behind. Initially, the LDDC argued that opportunities were being created and locals could benefit if they were able to take them[67]. With a budget around ₤40 million per year and a cumbersome task ahead, the LDDC expressed their intentions on their second Annual Report, in 1983, where they informed about the appointment of a Community Liaisons group but they also warned that:

63 Edwards,1992 p.10
64 Ibid, p.140
65 Foster, 1999 p.72
66 Hall, 1988 p. 358
67 Brownill, 1990 p.39

"*Consultation can too easily become an excuse for inaction in the face of lack of agreement since human beings are individuals and individuals rarely ever hold the same point of view or beliefs.*

Regeneration is cumulative and the Corporation has no intention of allowing the increasing momentum of development and change to slow down"[68]

Most of the expenditure of the first two years was dedicated to the acquisition of land. The LDDC had the power to enact Compulsory Purchase Orders, which facilitated the acquisition of land at low prices. Most of the land came from major landowners, such as the Port of London Authority, British Gas or British Rail[69]. The accumulation of land was a key mechanism to control development rhythm and quality. When the Corporation sold land to developers, they negotiated memorandums of agreement to determine the development conditions. Conversely, once they became landlords they could stop alternative proposals from belligerent boroughs. In addition to this, the purchase of land was an efficient income source. The LDDC could get important gains from the revaluation of the area. As the process advanced, they could reinvest the benefits in other operations. However, the land was initially sold under market's value in order to stimulate the activity. Many of the necessary environmental improvements were also directly undertaken by the Corporation. Developing companies were concerned with the costly preparation works. Extensive clearance on polluted sites was undertaken, river walls were strengthened and new services installed at the expense of the LDDC budget. This was a direct assistance to private developers that could purchase land below market price, avoid reclamation works and get net profits[70]

Fig.8-20 Docklands Light Railway. Initial proposal and extensions (LDDC-history)

68 LDDC, 1983 p.26
69 Brownill, 1990 p.43
70 Brownill, 1990 p.43

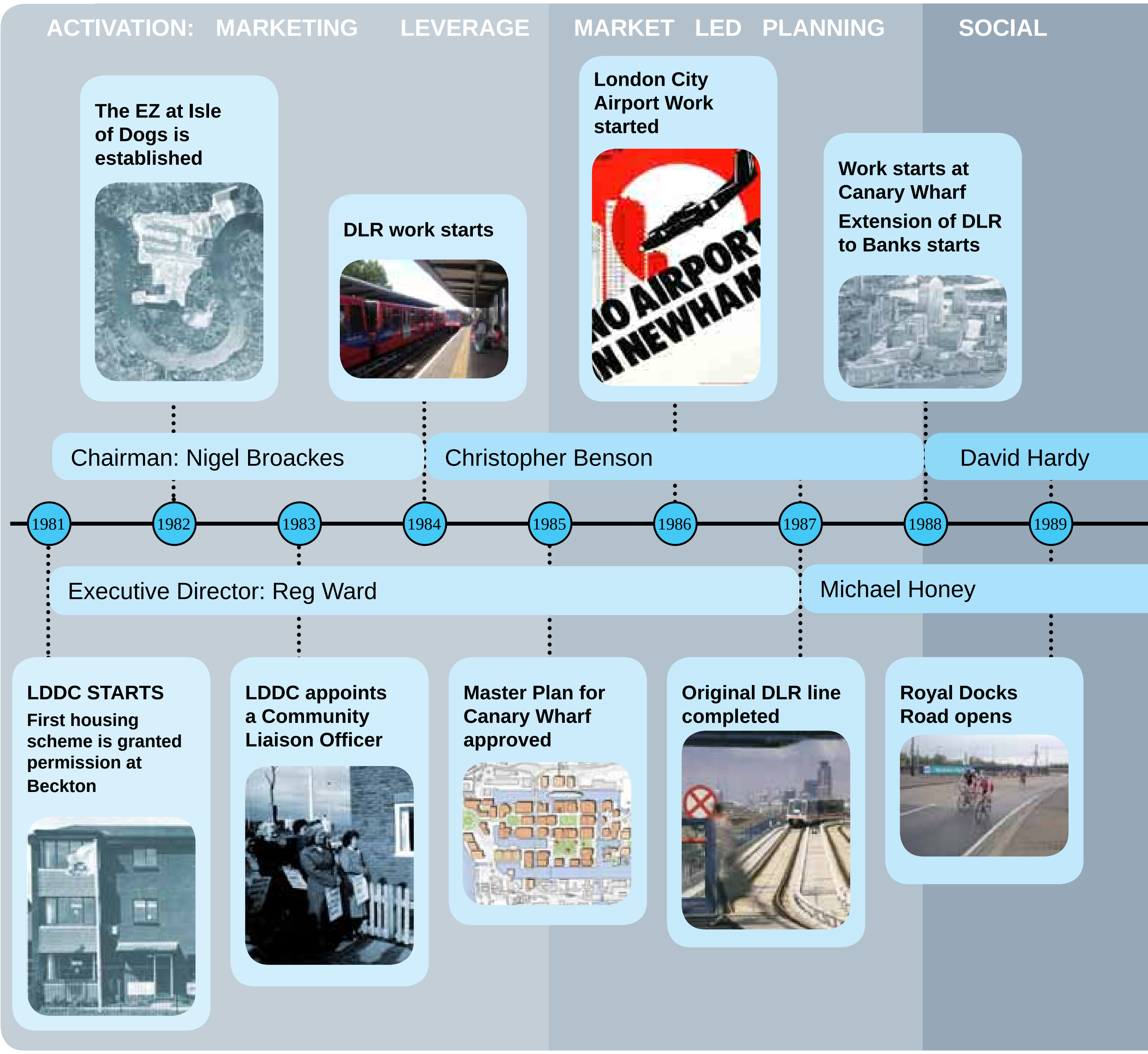
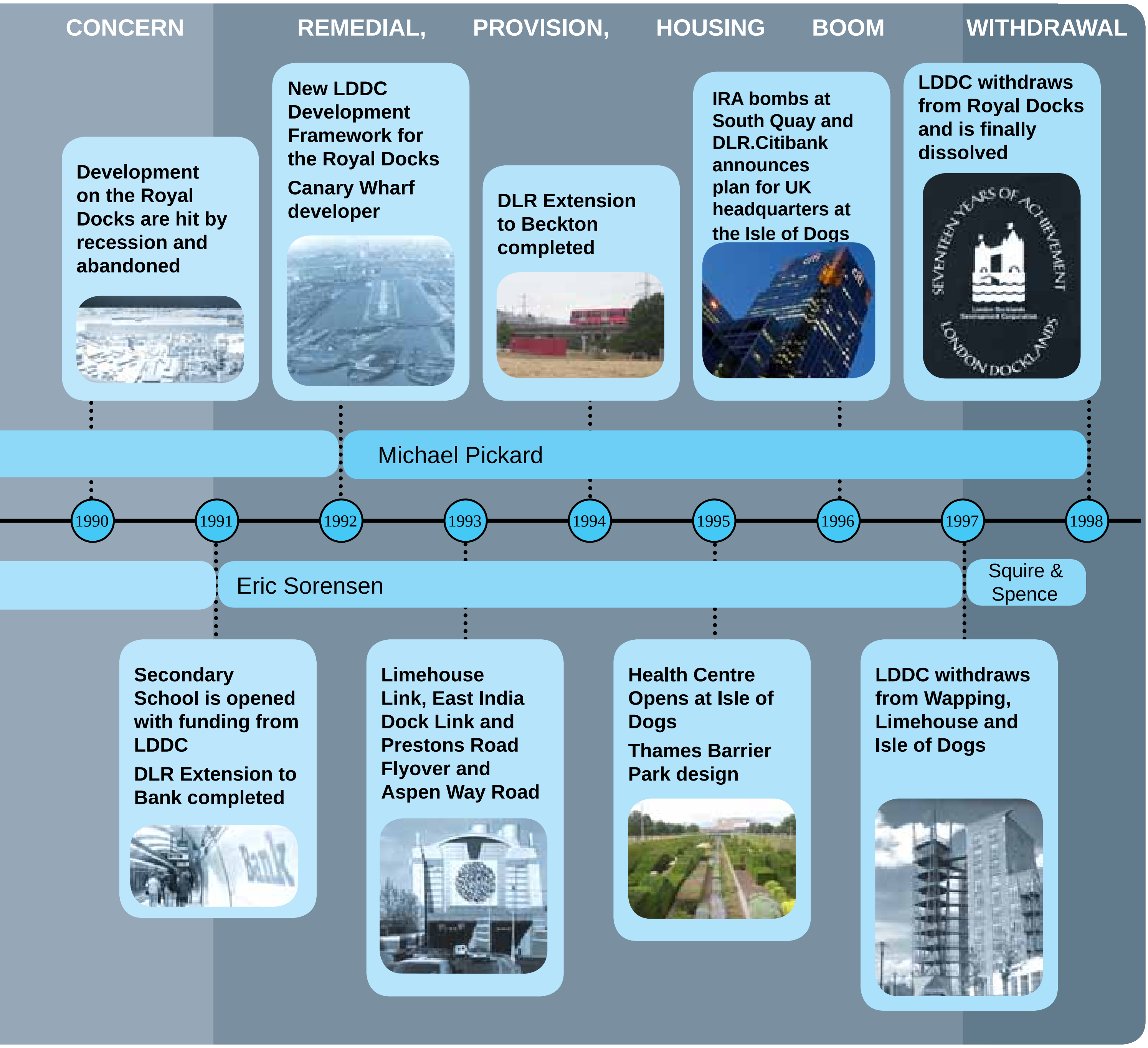


Fig.8-21 Timeline of the LDDC

After land acquisition and remedial, the second main target was the improvement of accessibility. The previous reports had emphasized that the existing roads were inadequate to absorb any additional traffic. The LDSP had proposed the extension of the Jubilee line but that solution had been dismissed as it was too expensive. Instead, the LDDC concentrated on a light rapid transit of small electric trains, the Docklands Light Railway (DLR) that would initially connect Tower Gateway with Island Gardens (south of Isle of Dogs) and Stratford. The DLR was, moreover, a dynamic advertisement of Docklands. The futuristic design, with computer-like colours and the elevated rails, intended to amplify the projection of a renovated image. Another visionary idea was the construction of a small airport at the Royal Docks. They were. at the same time, functional elements and marketing instruments to attract business and investors to the zone.



8.2.5.1.1. The Isle of Dogs Design Guide

A comprehensive study for the Isle of Dogs was commissioned in 1981 to David Gosling, who led a team of young engineers and recommended Gordon Cullen as consultant. It is doubtful that the Corporation had any intention of sticking to whatever proposals would come out from the study. The LCCD took it as an explorative instrument to assess the potential of the area through a series of visual proposals. It was an urban design guide to stimulate ideas for development and produce evocative images, a prospectus for developers. However, the design team was not completely aligned with the in-house architects and planners of the Corporation. Gosling felt that "without a total plan it was difficult to see how development could proceed in a coherent manner"[71]. The discrepancies between the designers led to a final report that contained three different approaches:

71 Gosling, 1996 p.127

1. The chief architect of the LDDC, Edward Hollamby, made a structural framework. He took a pragmatic approach to examine the schemes put forward by developers while incorporating some LDDC decisions, such as the retention of the docks and the conservation areas. The result was criticized as lacking any strong visual or structural framework[72], and as an amalgam of introspective developer's schemes that had totally disregarded their urban context.
2. Gordon Cullen took on the analysis of the visual structure, which he understood could unveil the "drama inherent in the site"[73] and provide a cohesive framework for the integration of individual developments. He created an schematic plan and a sequence of key vistas. His visual structure established three identities: the community circuit that linked the main nodes on the island, the water basin system and the most important, the Greenwich axis, as continuation of Wren's into the Isle of Dogs to Hawksmoore's St Annes at Limehouse
3. David Gosling prepared alternative conceptual studies which were based on a strong relationship between the public and private realms. He considered that a coherent public space was essential to absorb the inevitable variety of forms and styles that the approach of the LDDC would generate. His studies were relegated to the appendix and considered preliminary work as it resembled too much a planning proposal. The final Development and Design Guide was published in 1982 as an advisory guidance. As expected, it was largely ignored by developers and it became a mere marketing instrument.

8.2.5.1.2. Early development

The initial years were, however, successful in the terms of the Corporation. Despite the lack of a coherent plan for the urban realm, over 400 businesses had moved to Docklands by 1984[74].Most of them were small firms that had been attracted by the fiscal benefits. Due to the initial low cost of the land, the pioneer constructions were low rise with a moderate height. Neither British companies nor the City

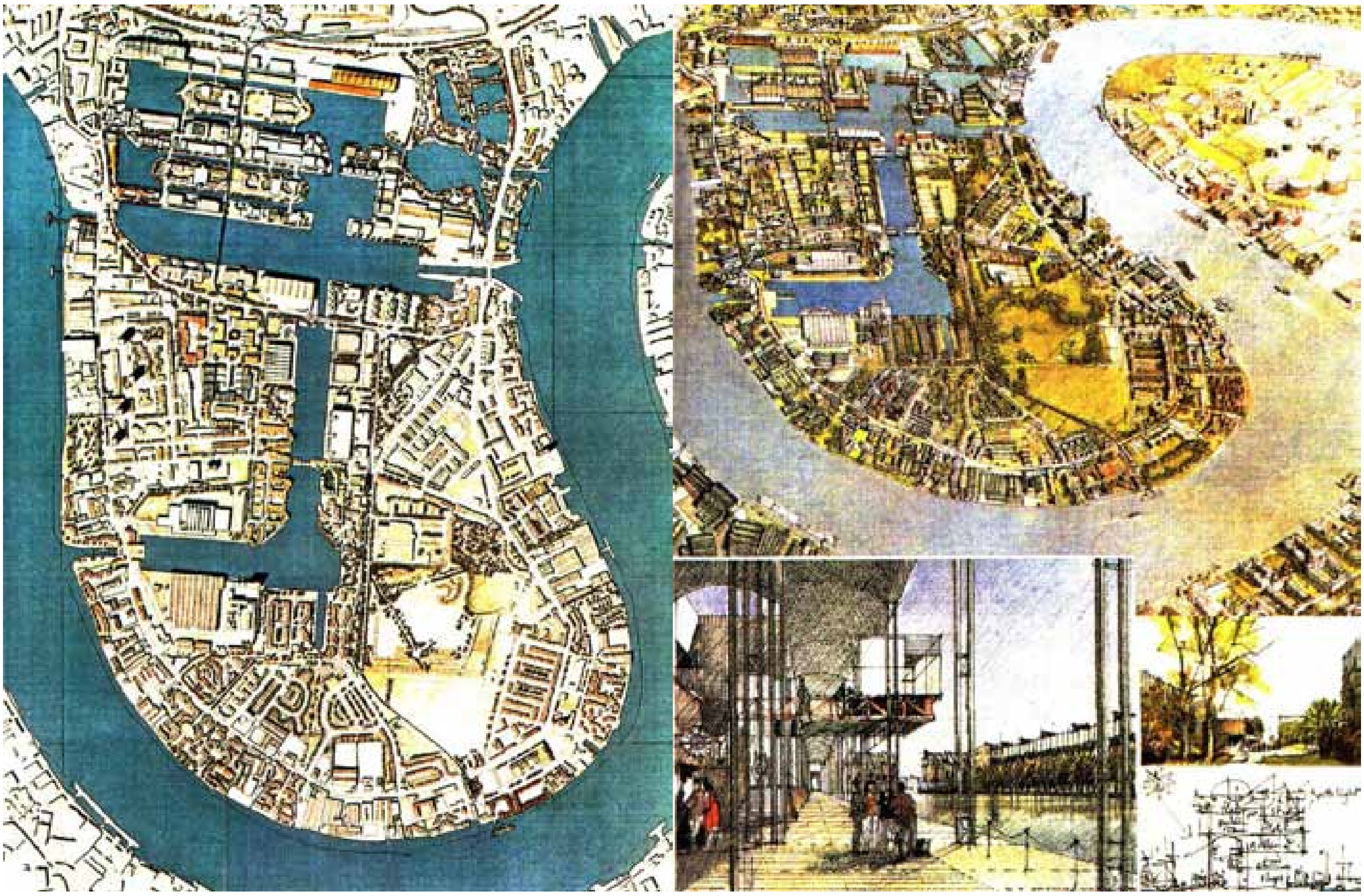


Fig.8-22 Hollamby's development framework (left) and Gordon Cullen's visual structure analysis (right) Source: Gosling, 1996

72 Gosling, 1996 p.128
73 Ibid, p.132
74 Carmona,2009 p.98

had a decided interest in creating a new office centre at Docklands. Therefore the executive director, Reg Ward, focused on foreign and telecommunication firms, offering little restriction for their antennas as incentive. Several media companies had already moved to the area before the LDDC, but the presence of News International and the Daily Telegraph were replicated by other firms in the following years (e.g. Reuters). The development model proposed by these firms was of a suburban type. The only public space was that of roads and parking lots, high standards were used in pavements and urban furniture (street lights, benches...) but the result lacked any urbanity.

Housing schemes had started a little earlier. A pilot project at Beckton was very successful, all the units were sold. Similar experiences at Wapping and Surrey Docks[75] triggered an immediate activation of the housing market. As prospective benefits improved, the value of the land started to increase. That was a positive aspect for the financial strength of the LDDC but it restrained the construction of affordable houses for local people.

In this first period, the resistance from residents was still mild. There were several community groups, such as the Docklands Forum, the Association of Island Communities or the Docklands Consultative Committee, which had been formed in the seventies but there was not a universal position. The LDSP had raised some expectations regarding the industrial activity and provision of housing and facilities. Nevertheless, many locals were highly sceptical since they had heard many promises but witnessed no change at all. They were not really aware of the extent they would be affected by the regeneration until the big developments started to change the skyline of the Isle of Dogs. In that moment the local reaction became extremely active.

8.2.5.2. 1984-1991 Canary Wharf development. Consolidation of market led planning

As Gosling pointed out, it is ironic that while the LDDC was decidedly against urban design plans (as they would restrict development), they warmly welcomed a "master plan with strict design guidelines produced by an external agency"[76]. In 1985 an Amercian consortium led by Travelstead (the same developer of the Arts Hotel in Barcelona's Olympic Village) presented a masterplan designed by Skydmore, Owens & Merrill (SOM) for the West India Dock area. It took the name of a former warehouse, where fruits from the Canary Island were unloaded, the **Canary Wharf**. The project proposed 800,000 square meters of office space, 2 hotels, 9,250m² in services and over 40,000m² in shops and restaurants. It would be the largest commercial development in Europe.

The fate of Canary Wharf cannot be explained without the economic context. A financial landmark known as the "Big Bang" was a key factor. It consisted on a package of measures to deregulate the financial market and thus reactivate the City as a competitive financial centre. It notoriously meant the end of the separation between retail banks and investment banks, which for some observers was a prelude for the 2008 credit crunch[77], and the introduction of Wall Street practices and modern technologies (i.e. computers) in the old-style customs of the City. The electronic trading system allowed a substantial increase in the number of deals and new operators. The market activity rose to levels that the old City could not handle. American banks were some of the main beneficiaries and they needed space for their British headquarters. It is uncertain whether the Thatcher administration had devised the whole process as a coherent strategy but the sequence of events and governmental decisions matched perfectly. In 1982 the Enterprise Zone was created in the Isle of Dogs, development started slowly and modestly. Four years later the financial market is deregulated, creating a massive demand for new office space beyond the capacity of the City. Canary Wharf becomes a convenient and attractive alternative. The City did not welcome the new competitor to the east though.

To ensure the feasibility of the project, important transport and infrastructure provisions had to be undertaken. The extension of the DLR until Bank (at the core of the City) and the Limehouse Link, which would traverse the Isle of Dogs, were estimated in £250 million. It would be assumed by the LDDC[78]. However, the negotiation of a Master Building Agreement was delayed for over 18 months and the consortium withdrew due to financial problems. The favourable conditions (all the EZ benefits plus the explosion in the financial sector) attracted a powerful Canadian developer, Olympia & York. It was considered the world's largest and best managed property development firm[79]. It had recently had a great success in developing the World Financial Centre in Battery Park's New York and was confident on repeating a similar investment in London. It introduced some changes in the project, which would now reach 1 million square meters of office space, and it committed itself to contribute with £150 million to the extension and upgrading of the DLR.

As the project was in the Enterprise Zone, neither planning permission nor consultations were required. The outrage of local communities was vividly expressed as the largest development in Europe would be approved with less scrutiny than "a planning application for an illuminated sign on a fish and chips shop in the East India Dock Road"[80]. However, for Olympia & York, the design was an important aspect and the laissez-faire that the LDDC had applied so rampantly was not on its agenda. In order to protect their investment, they adopted a masterplan approach. A detailed code would ensure

75 Brownill,1990 p.69
76 Gosling,1996 p.132
77 Stewart & Goodley,2011
78 Fainstein, 2000 p.183
79 Ibid, p.181
80 MP Nigel Spearing quoted in Brownill, 1990 p.56

Fig.8-23 Canary Wharf. Top left: previous state in 1987 (SOM). Top right: The Olympia & York’s proposal of 1988 (Naib, 1990). Center: aereal view in 2008 (SOM). Bottom: Olympia & York’s development plan of 1988 (Cox, 1995)

a minimum environmental quality and the coherence of the composition. The plan by SOM organized over 20 building sites on a 20 ha extension. The prescriptions of the plan covered from building elevations and window rhythm to materials and urban furniture. As in the case of the Isle of Dogs Design Guidelines (by Gosling & Cullen), the project was profusely illustrated with detailed plans and perspectives. It transpired a certain flavour of Chicago School mixed with postmodern design. According to Fainstein, one of the major design objectives was to create the illusion of a natural growth[81]. Individual building designs were commissioned to different architectural firms (Cesar Pelli, I.M Pei and SOM) to ensure architectural diversity. A different opinion was expressed by Edwards, for whom the rigid composition of the elevations, together with the selection of timeless materials and the repetition of compositional elements, created a “disappointing sameness”[82] that undermined the rich spatial complexity of the masterplan. Not all the criticism was substantiated with disciplinary terms as the dislikes were expressed by harsh metaphors: from “a lot of American crap”[83] to the sexual symbolism of the Canada Square tower or the image of “Architectural Zoo, with a different beast in each plot”[84]. 25 years after the design of the masterplan, Canary Wharf has become a distinctive landmark of Docklands but it is equally an icon of corporative development and dehumanized urban design. The association of the architectural expression of Canary Wharf with the financial sector, which has distressed the world in recent years, may have even worsened the perception of this development model. The sheer magnitude of the buildings made them awkward elements in London´s skyline. Moreover, the City had to succumb and relax its traditionally conservative urban standards in order to compete with the new symbols of power which were emerging at the East End. A series of gigantic skyscrapers are now scattered around the City and elsewhere (Saint Mary Axe, the Shard, Broadgate, Strata) endangering the traditionally domestic scale of London streets.

8.2.5.2.1. Social response

The construction of Canary Wharf’s colossal buildings unleashed the most intensive wave of local opposition. The project was the final straw in the line of LDDC insensitive actions to the eyes of residents. The Corporation did not conduct any real consultation with the locals, it rather used the Community Liaison officers to inform and sell decisions that had already been taken. The main concerns of the locals were unemployment and the shortage of affordable housing. However, the construction of social housing was not a priority in the regeneration agenda since the plan was to increase the ratio of owner occupation. From 1981 to 1989 the proportion

Fig.8-24 The iconographic power of the 1 Canada Square has been used in a number of publications, both general and site specific

81 Fainstein, 2001 p.183
82 Edwards, 1992 p.72
83 Anonymous London architect quoted in Carmona, 2009 p.103
84 Buchanan quoted in Carmona, 2009 p.103

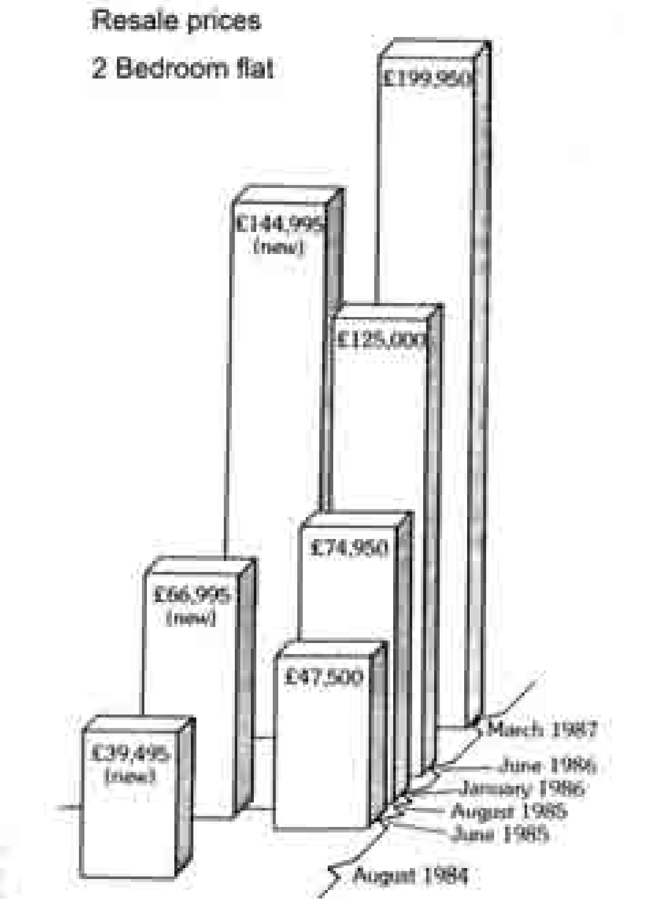


Fig.8-25 Resale prices on a two bedroomed flat on Clippers Quay . Original asking price in the left-hand column, re-sale in the right (Foster, 1999)

of council tenants decreased from 95% to 55%[85]. The housing activity boomed after the early successful experiments at Beckton and, subsequently, prices skyrocketed. By the mid eighties, most housing buyers were not prospective residents but investors and, more specifically, speculators. They paid the deposit before the houses were built in order to sell it soon after, with a considerable gain. (fig. 8-25) .The housing typologies did not respond to local needs either. Small two bedroom apartments were the prevailing type (67% of new dwellings had one or two bedrooms and 77% were flats in 1987)[86] . They were not suitable for the families of Docklands. The new residential developments were designed with potential newcomers on mind, whose archetype responded to white, male, young professionals, working in the service sector at the City or the West End[87]. The stereotype of newcomers as yuppies was widely spread, although it may have been a false perception, considering that two thirds of the population in 1987 were residents of the East End before the LDDC had stepped in[88]. However, the regeneration was, undoubtedly, bringing about a gentrification process. On top of this, the pressure on social housing was increasing since 1981, when the “Right to Buy” scheme[89] was passed by the Thatcher administration. New generations of Docklanders

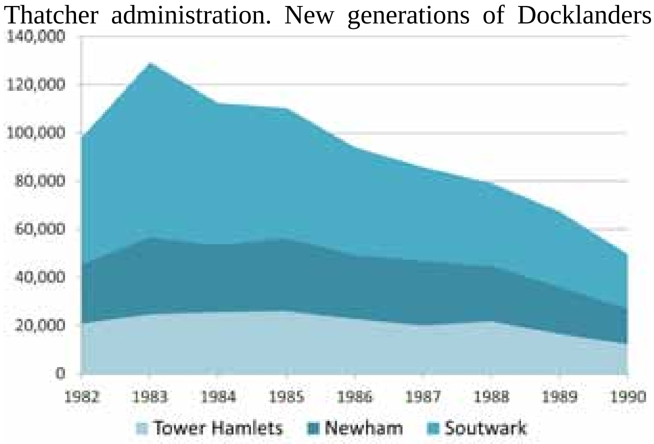


Fig.8-26 Docklands boroughs housing investment programmes from 1982 to 1990 in £ (contains data from Brownill, 1990)

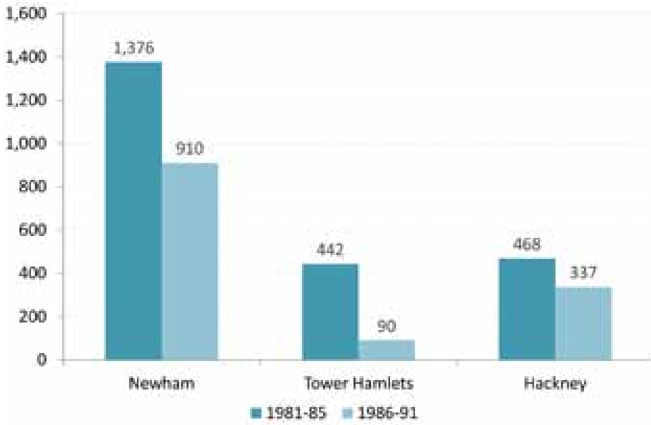


Fig.8-27 New dwellings completed by local authorities in Docklands boroughs, 1981-1991 (contains data from Rix, 1996)

were in need of affordable homes but most of them could neither afford one of the so considered affordable schemes nor access a council flat (fig. 8-27).

The new jobs did not contribute to alleviate the economy of local families. Research has indicated the complex relationship between employment creation and access at local level[90]. Many of these studies have suggested that jobs creation in a metropolitan area may have a minimal effect on local unemployment[91]. It has been unveiled that most of the new positions (70% to 80%) tend to be filled

85 Brownill, 1990 p. 67
86 Foster, 1999 p.126 Brownill, 1990 p. 70
87 Brownill, 1990 p.80
88 Foster, 1999 p.160
89 A policy that allowed council tenants to acquire the homes they had been renting with important discounts. It would eventually cause a reduction of council homes because they were not replaced by new developments.
90 Church, 1987 Morgan, 1993 Rix, 1996 Docklands Forum & Birbeck College, 1990
91 Church, 1987 p.194

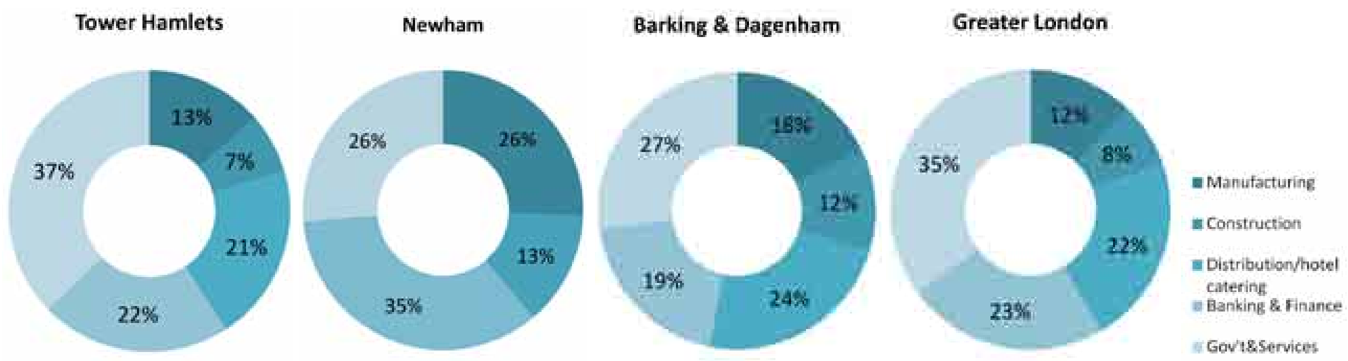


Fig.8-28 Main sectors of employment in East London boroughs in 1991 (contains data from Rix, 1996)

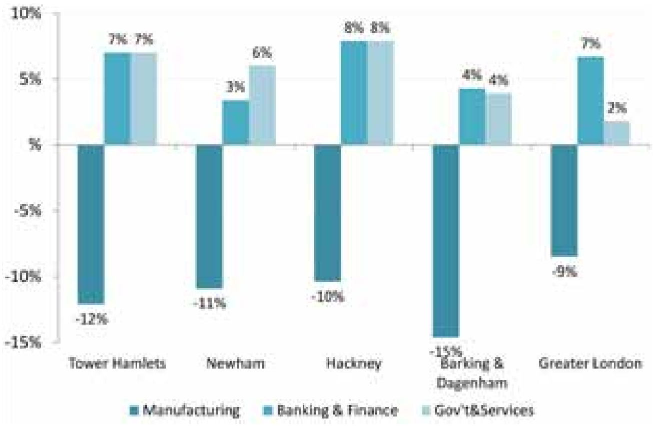


Fig.8-29 Key aspects of industrial change between 1981 and 1991 (contains data from Rix, 1996)

with employees who were recruited from other jobs and were, consequently, lost for the local labour market. It has been, likewise, demonstrated that the main effect of major employment growth, at any specific location is the adjustment of commuting patterns in the region[92]. Surveys conducted in the Isle of Dogs and Newham confirmed that less than 20% of the interviewed employees were living in the area[93]. Jobs vacancies were filled by commuters who were previously working at the City or the East End and not by local people.

Indeed, the explicit strategy of the LDDC was not the reduction of unemployment but the activation of economic activities in the area. It was hoped that the benefits for local people would be a spin off of any new economic development. Therefore, there was not a particular interest from the LDDC in the type of jobs that were being created. However, the Corporation was aware of the mismatch between the jobs they sought and the skills of local people, mostly drawn from low skilled and manual occupations. It implemented several educational and training schemes to "ensure that there is adequate skilled labour to meet the demand of employers coming to Docklands"[94]. Following pressures from local associations, the LDDC included a "local labour clause" in construction contracts by which the contractors should hire local workers. The real effect of the clause was minimal (less than 1% of workers were residents of Docklands) as the Company was reluctant to impose conditions to developers and it added a "where possible" extension to the "local labour clause"[95].

In summary, the profile of local jobs changed, towards finance and service sectors (from 30% to 60% of the total)[96]. Most of these jobs were relocations rather than new posts and they were primarily filled with employees from across London commuter region. The belief that local people could eventually benefit from a trickledown effect was not apparent, since their skills did not match the new profile of the labour market. Consequently, deprivation and unemployment levels remained among the highest in London and even in the United Kingdom.

The instruments devised by the local community to manifest their dissatisfaction were varied and diverse. The main strategy during the initial years was to oppose the plans and damage the public image of the LDDC, which was very valuable for the Corporation. There were demonstrations and protests in the streets. By the end of the eighties, protests took a cultural dimension. Community activists organized campaigns with a strong symbolism to relay the message more effectively. Some of them are now recorded in the Museums of London and Docklands: a symbolic funeral where black banners and coffins represented the death of the local community (fig. 8-30) or the sabotage of a "foundation stone" act in Mudchute, where bees and sheep were released in presence of the Governor of the Bank of England and other personalities.[97] Other strategies included leaflets, handouts and posters[98] as well as regular plenary sessions to debate specific issues and monitoring reports about the activities of

92 Ibid
93 Ibid p.198
94 Docklands Consultative Committee, 1988
95 Church, 1987 p.202
96 Brownill, 1990 p.94
97 Foster, 1999 p.145
98 See CSpace,2013 to check out some examples of the Docklands Community Poster Project

Fig.8-30 Campaigns against the LDDC from the local community. From top left, clockwise: Funeral for the death of the local community. Release of sheep and bees as protest against the closure of Mudchute Farm. People's Armadas simulating a naval attack on the Parliament. A meeting to coordinate a road-show (source: CSpace,2013)

the LDDC. However, there was not an unanimous response as many residents were overwhelmed by fatalism and they considered that the battle was useless or not worthwhile[99].

Local action was occasionally fruitful. In Surrey Docks and Swan Road, land for council homes was obtained after pressure from local groups. Housing improvements were also subsidized in the areas affected by the DLR. But perhaps one of the most emblematic cases was the campaign against the proposed closure of Mudchute farm, an urban farm and community centre, and its replacement by office blocks[100]. The event to celebrate the Master Building Agreement of Canary Wharf, in which the bees and sheep were released by campaigners, was sabotaged as part of the boycott. The broad media coverage that the LDDC had organized for the event gave national projection to this performance. The farm has remained open up to present day.

In the long term, the LDDC was forced to reconsider their approach to the local community. By the end of the eighties, the regeneration strategy was being criticised, not only by native docklanders but also by newcomers and even developers. The broad flexibility and lack of prevision caused deficiencies which undermined urban quality. The physical environment was poor, there was a shortage of basic facilities (schools, health centres or groceries), few green areas and the transport network was inadequate. The abolition of strategic planning ended up as a lack of strategy. In 1988 Michael Honey was appointed as executive director of the Corporation to address the relations with the local community. The new strategy encouraged closer collaboration and consultation with local forces. The department of Community Liaisons was given funds and power to ensure the creation of social facilities and affordable housing. The attitude of the boroughs (mostly were labour controlled) and associations changed from confrontation to collaboration. There was a real window to achieve something for the local community. When Olympia & York took over the project of Canary Wharf, they were well aware of how important was to establish communication channels with the locals, so as to avoid the problems that their predecessors had had to bear. They hired a former local representative (Peter Wade) and agreed learning and skills programmes. Other big companies followed the

99 Brownill, 1990 p.112
100 CSpace,2013

Fig.8-31 Posters and photo-murals were used to highlight the key issues that affected local people. The opposittion to the LDDC approach to regeneration had an strong cultural component (source: CSpace,2013)

same path (BT, British Gas), which made the opposition to regeneration less combative. After two years of Honey's Community Division, the positive perception towards the LDDC had increased from 36% to 49%[101]. Unfortunately for them, some developers were suspicious on the excessively social shift taken by Honey. They advocated for a turn to purely physical regeneration, investing in so much needed infrastructure and less in housing refurbishment or training programmes. In 1991 the Department of the Environment replaced Honey by Eric Sorensen, a loyal officer of the DoE, and the regeneration agenda was revised in order to reinforce transport and business incentives as the main priorities of the Corporation.

8.2.5.3. 1991-1998 The fall and rise of Canary Wharf. The LDDC withdrawal

On Monday 19th of October 1987 the stock markets around the world crashed. This event started an economic crisis that hit the financial sector very strongly. The consequences in the short term were a sharp increase in redundancies in many of the firms established at Canary Wharf and a period of contraction that reduced the number of potential tenants. Developments that had not been started were halted and those that could not be stopped had to offer incentives to attract a clientele. Olympia & York was caught at the bottom of the cycle as it had stepped in by mid 1987. The economic strength of the company allowed it to keep the investment in Canary Wharf but by 1990 liquidity problems started to become apparent. In the summer of 1992, 53% of the office space nearing completion remained unlet and little retail had been rented either[102]. In addition, the commercial paper of the company was downgraded, which made it impossible to refinance its short-term debt and obligations, including the first instalments on the Jubilee Line extension. That same summer Olympia & York was put under administration by a U.K. bankruptcy court.

Most observers agreed that there was no a single reason but a combination of factors that propitiated the collapse of the real-estate giant[103]:

- The competition with the City, which finally relaxed its strict regulations in a critical moment, when Canary Wharf was striving to establish.
- The crisis in the financial sector and office market caused by the Black Monday's crash
- Inability to provide adequate transportation links on time
- Inability to understand British context. Fainstein quotes a developer who suggested that "North Americans have no sense of place, or of history. He (Paul Reichmann, owner of Olympia & York) didn't realize that British people and business are tied by invisible threads to places"[104] On that sense, Canary Wharf had a serious disadvantage with its competitors of the City, trading activities still maintained a certain sense of tradition that had much to do with the buildings, streets and pubs of the old fabric. Olympia & York struggled to attract British tenants, who

101 Foster, 1999 p.238

102 Fainstein, 2001 p. 187

103 Carmona 2009, p.109 Fainstein 2001 p.189

104 Fainstein, 2001 p.187

showed their reluctance to break up with their links at the City.

The LDDC was not immune to this crisis and, despite the increasing flow of public funds from the central government, went into financial troubles. Without the money from Olympia & York, infrastructure works were taking more funds than the Company had expected. When Sorensen took over by mid 1991, he announced an austerity plan that included over 200 redundancies[105]. Critics rushed to attribute the failure in Canary Wharf to the regeneration approach of the conservatives and the LDDC in particular[106]. Urban analysts could not refrain from tearing apart the whole regeneration process, with a disregard of the external factors that influenced the temporal collapse of the real estate market. According to Carmona[107], this may have responded to the general dislike of Thatcher's policies among urban theorists, who were blinded by the opportunity to present a massive piece of evidence against them. From 2013 perspective, and notwithstanding the later recovery of Canary Wharf, it cannot be denied that the flexible, market-driven planning approach was too exposed to the intrinsic fluctuation of the market. Even private developers were uneasy with the uncertainty derived from excessive flexibility and they demanded a sound framework to ensure certain stability and ground rules.

Despite the gloomy perspectives of the early 1990s and the general disdain of urban commentators, Canary Wharf did recover. The former chairman of Olympia & York, Paul Reichmann, managed to retrieve control over the development only three years after it went into administration[108]. The stubbornly move of the real-estate tycoon proved right when soon after the scenario started to change. The British economy bounced back and (partly) thanks to a broad marketing campaign, Canary Wharf became an attractive investment once again. Vacant offices were being occupied at a remarkable pace (47% in 1992, 80% in 1992, 98% in 2000[109]) and some of the tenants were now prestigious British firms (e.g. Barclays) which contributed to improve the perception of the place beyond the image of a purely American enclave. The capacity to compete with the City was favoured when the DLR and Jubilee lines extensions were finished and the Limehouse link was completed. Public transport was now an integral part of the development strategy. The initial low rents could be gradually increased in the way the prestige of the address as financial district grew.

Major construction activity was resumed by the turn of the century, with the construction of two towers on the remaining plots of Heron Quays for HSBC (arch: Foster & Partners) and Citigroup (arch: Cesar Pelli). The phallic symbolism of the formerly isolated 1 Canada Square could be, finally, balanced with the neighbouring skyscrapers. The new designs abandoned the post-modern classicism to adopt an equally placeless international language based on glassy, shinny, "high-tech" towers and deep plan blocks. The outburst of critics to the design of buildings that characterized the first phase turned weaker as British architects replaced American firms as lead designers (Farrell, Foster, Future Systems, Ron Arad...). Even former campaigners such as Richard Rogers (he had described Canary Wharf as an "unsustainable development"[110]) would contribute with his own glassy, shiny tower designs (Wood Wharf, later taken over by Farrells). A positive side effect of the awakening of construction was the completion of large pieces of the urban landscape and

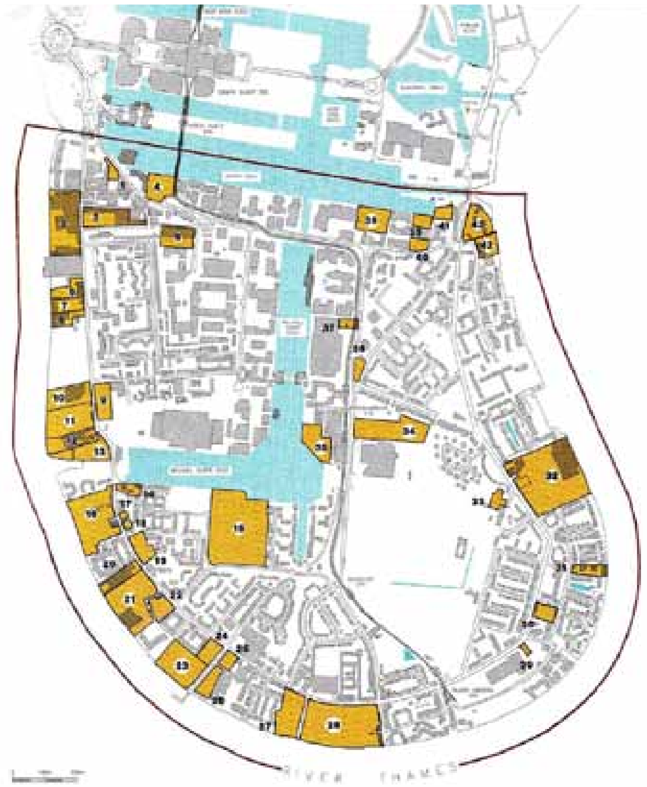


Fig.8-32 Isle of Dogs Development Framework. Opportunity areas, later residential enclaves (LDDC, 1994)

a renewed interest in the activation of the street with active frontages, more greenery and some small parks.

In the rest of Docklands, the opportunity-based approach of the LDDC had remained in operation. The crisis of the early nineties had had a broad impact as activity had almost ceased. The subsequent recovery brought another housing boom, which was particularly intense in the Isle of Dogs. In 1993 most of the vacant homes had been sold (from 600 to 68

105 Fainstein, 2001 p.189
106 Carmona, 2009 p.109
107 Ibid
108 Fainstein, 2001 p.190
109 Ibid
110 Carmona, 2009 p.110

vacant units[111]) which fostered more and larger development proposals. The following year the LDDC published a plan of the Isle of Dogs: The Isle of Dogs Development Framework (IDDF). The plan had an advisory character, since the LDDC was not a planning authority (it could exert planning control but could not create statutory plans) and the Tower Hamlets council was preparing their own Unitary Development Plan. The plan identified the main opportunity areas left in the island, together with specific design guidelines for each of them. It intended to avoid some of the flaws of previous experiences by highlighting river access, views and the importance of urban design[112]. However, developers would ignore most of the propositions and the identified plots would be gradually developed as low and medium density condominiums, creating a continuous sequence of private enclaves along the riverside.

The housing boom did not alleviate the accommodation problems of the original community. The construction of new infrastructures in East London had forced the rehousing of a large population. In addition, the “Right to Buy” programme had induced a net loss of available council homes. As a result there were many more families looking for council accommodation than available units. In 199,5 there were 7,500 persons in the waiting list of Tower Hamlets and over 1,000 in the Isle of Dogs alone[113]. The Isle’s district council established priority criteria according to the level of deprivation of the applicants. The first to enter the scheme were the homeless. Most of them were Bangladeshis and Bengalis that had been expelled from other areas of the East End due to road constructions[114]. The local community, composed of white working class, low skilled people, saw these new groups as foreign competitors who were getting the few available social homes in the Island, while their sons had to leave somewhere else. There was an increasing association of the area with racism, a perception that reached a peak when the British National Party (BNP), a nationalist party with xenophobic ideas, beat the labour candidate in the Isle of Dogs in the Parliamentary elections.

The end of the period is marked by the dissolution of the LDDC, which translated into the gradual withdrawal from the different zones of Docklands, from West (Wapping, Limehouse) to East (Royal Docks was the last zone). The new labour party led by Tony Blair had gained the general elections and closed the tap for new funds in Canary Wharf and Docklands. The Corporation handed on the rights and pending liabilities to a number of bodies (British Waterways, local boroughs...)[115]. At the time of its withdrawal, they declared that there was a self-sustained development in all areas within the LDDC boundaries, with the exception of the Royal Docks, where plans for new academic facilities (East of London University Campus and primary and secondary schools) and a large exhibition centre (Excel) were sealed in the last six months of the LDDC. The last annual report of the Corporation declared the regeneration as a great success, based on the concentrated effort of a single-minded organization and justified by the following figures:

- 1984 acres of derelict land reclaimed
- 25 million sq.ft of commercial /industrial floorspace built
- 24,046 new homes built
- 83,000 people living in London Docklands
- 85,000 people working in London Docklands
- 11 new primary schools
- 2 secondary schools
- 3 post-16 colleges
- 9 vocational training centres
- 5 new health centres and 6 centres redeveloped
- 144 km of new and improved road and DLR
- 94 awards for architecture, conservation and landscaping
- £1.86 billion public sector investment
- £7.7 billion private sector investment[116]

Florio and Brownill[117] pointed out the scarce attention that academic community paid to the last years of the LDDC in comparison to the intense flow of commentary during most of the first decade. It could be partly explained, they argued, by an ideological shift in planning towards a greater emphasis on the market perspective (to address its imbalances) that made LDDC approach less hard to digest. The success of the Corporation was strongly supported by the figures they presented in their last account. Canary Wharf was no longer a hopeless “ghost town”[118] but a dynamic financial centre, a new population of workers and residents were attracted to Docklands, which were now well connected with London (DLR, Jubilee and Docklands Highway) and even with the continent (City airport, future Crossrail). Therefore, the arguments to challenge the LDDC story are not to be found in the outputs but in the process. Whether the end justified the means and whether there was an alternative to the LDDC approach are the main questions that were addressed in the few critic voices that remained after the Corporation’s withdrawal. Florio and Brownill defend that, if regeneration has been achieved, it was despite, rather than thanks to, opportunism and the lack of strategic planning[119].

111 LDDC, 1994b. p.10
112 Carmona, 2009 p.116
113 Foster, 1999 p.258
114 Ibid
115 LDDC, 1998 p.15
116 Ibid, pp.2-3
117 Florio & Brownill, 2000
118 A reference made by Fainstein the first version of “The CIty Builders”, rectified in the second edition after Canary Wharf recovery
119 Ibid, p.56

For instance, the fact that infrastructure provision had to be reconsidered from scratch when the Canary Wharf came to the scene meant a greater cost had it been planned from the outset. The formula of leverage-planning was initially devised as a way to reduce public spending but the experience with the LDDC showed that it restrained the ability of local planning authorities to determine land uses and development areas. Private developers would only operate when there is a solid perspective of profits or the risks have been strongly subsidized with taxpayers' money. In addition, the influence of locally elected bodies was minimized when the foundation chart of the LDDC established that it was only accountable to the central Government. It was considered undemocratic.[120] Although the faults of the Docklands experience were not openly admitted in the LDDC farewell discourse they could be subtly read between the lines. The demise of planning that its founders advocated did not occur. Rather, a refinement of planning principles to colligate market and public interests took place. Partnerships and greater flexibility within a strategic framework were some of the outcomes from this process that were integrated in planning thought and practice thereafter.

8.2.5. 1998-2013 Docklands and The future East

The end of the LDDC era was a turning point in inner city regeneration. The Labours' comeback to Downing Street brought another shift in the planning approach. The new discourse aimed to reintroduce strategic planning with people's needs at the centre of the urban debate. The agenda for this "new deal" was commissioned by the Deputy Prime Minister John Prescott to an advisory board, namely the Urban Task Force, chaired by Richard Rogers[121]. They produced the document "Towards an Urban Renaissance" in which many of the concepts and terms of inner city planning of future years were advanced. Aspects such as innovation, social and environmental sustainability became common targets in all city policies of the new millennium. The means to achieve these objectives included partnerships across different agencies, strategic planning and a strong design framework. European cities such as Barcelona or Amsterdam were seen as paradigmatic models to be emulated. The design-led Barcelona model was especially praised, not only by the Task Force but also by the RIBA, which awarded this city with its Gold Medal. The ideal model was characterised as a dense, compact city with mixed uses and various centres. A dulcified version of the UDCs was proposed as vehicle for regeneration, namely Urban Regeneration Companies. They would work in partnership with local people and authorities. Similarly, the equivalent to the Enterprise Zones was defined as Urban Priority Areas[122].

120 Ibid, p.59
121 Urban Task Force, 1999
122 Ibid, p.142

The regional government of London was re-established in 2000, under the name of Greater London Authority. Its foundation Act stated that a London Development Agency would be created and a spatial development strategy should be prepared and published as soon as possible. These commands would be accomplished by 2004, with the publication of the London Plan. It dealt with issues whose scale and importance were strategic for the whole London region (transport, environment...). All boroughs' development plans should conform to it[123]. In line with densification policies advocated by the Mayor Livingstone and his advisor Richard Rogers, a series of Opportunity Areas, most in the inner city, were designated by the plan. Those areas were places with capacity to accommodate substantial new jobs or homes, where density could be increased. Five Opportunity Areas were located at Docklands: Isle of Dogs, Deptford Creek, Royal Docks, Millennium peninsula and Woolwich. The Plan also set that a Planning Framework should be elaborated to provide a "sustainable development programme" to those opportunity Areas, having an advisory character[124]. Likewise, Areas for Regeneration were designated to be considered by the boroughs in the elaborations of their Development Planning Documents (DPD). The areas thus designated neither included the Isle of Dogs nor Surrey Docks, which indicates that they were already considered as completely regenerated zones.

The transport investment, especially the construction of the Crossrail line[125], would allow carrying further population (residents and workers) from and towards Docklands. The Plan established specific targets for the area to make sure that the strategy towards densification of central districts was taken on by the local boroughs. The overall increase in the former Docklands area represents over 30 new dwellings and 65 new jobs per hectare (table 8-2).

Table 8-2 Densification of Opportunity Areas as in the London Plan 2004-2008 (data from Mayor of London 2008)

Zone	**Area (Ha)**	**New Jobs 2001-2026**	**New homes 2001- 2026**
Isle of Dogs	363	+110,000	+10,000
Royal Docks	636	+5,500	+14,000
Lower Lea	1,446	+50,000	+32,000
Deptford Creek	165	+4,000	+8,000
Millennium Peninsula	355	+7,500	+15,000
Total Docklands	**2,602**	**+177,000**	**+79,000**

123 Mayor of London, 2008
124 Ibid, p.A77
125 The Crossrail will connect Shenfield (Brentwood, to the East) and Abbey Wood (Greenwich) with Maidenhead (to the West) thus crossing central London.

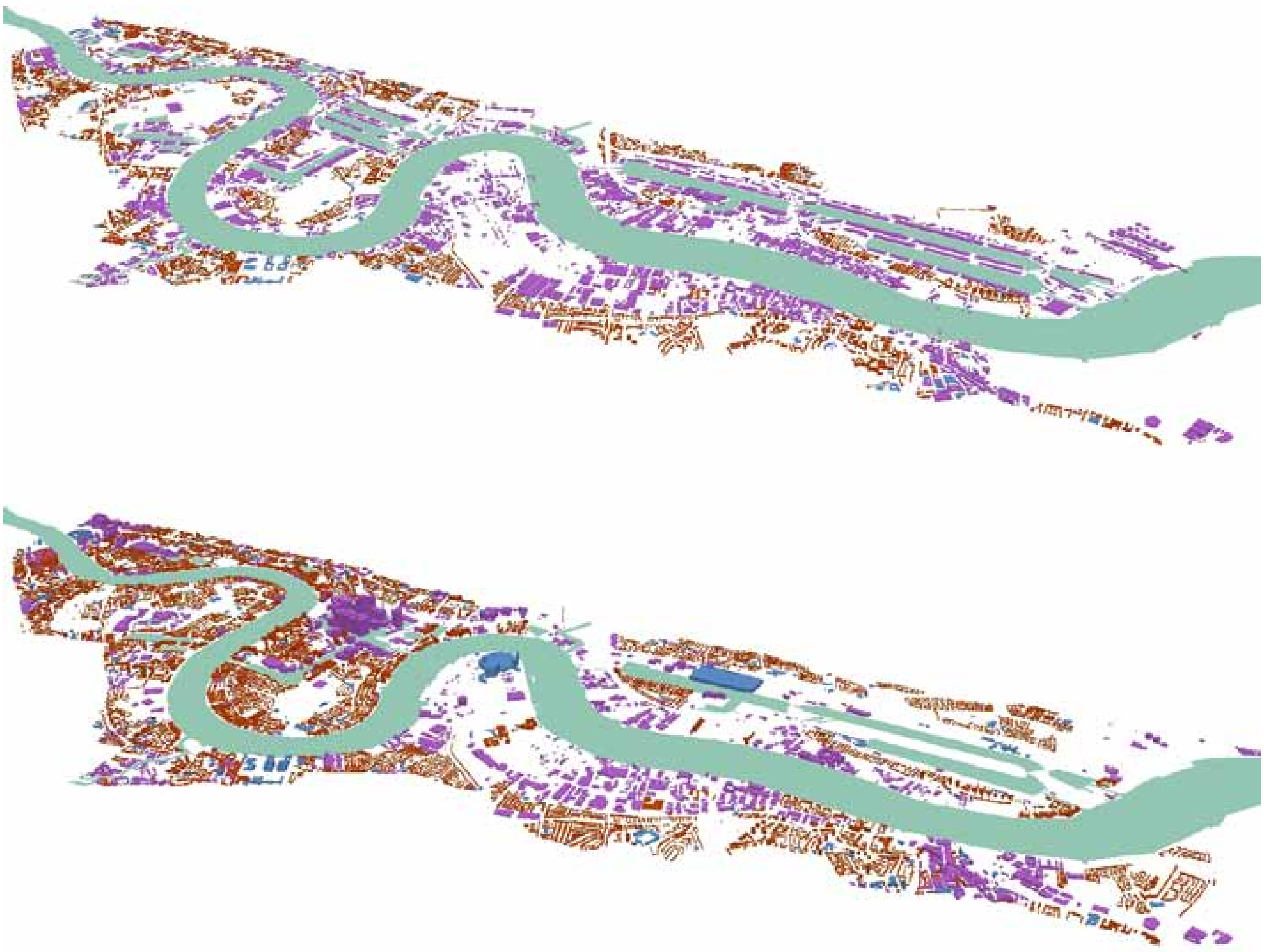


Fig.8-33 Axonometric views of Docklands showing the transformation in land use and building density from 1981 (top) to 2012 (bottom)

8.3. 1981- 2012 The physical transformation

Despite the fact that the area of influence of the so called London Docklands covers over 2,000 hectares along the River Thames, its regeneration has been often identified with the Isle of Dogs and, more specifically, with the development of Canary Wharf. Undeniably, the financial hub has become the main of the new centralities brought about after the transformation process. It has concentrated the largest proportion of new constructions and employment, and its tall buildings exert a symbolic and physical dominion over the surrounding territory. However, the evolution of the area in the last thirty years was heterogeneous and diverse, as each zone adapted in a more or less organic way to its intrinsic conditions, primarily defined by location, connectivity and the presence of singular features (heritage, structural hubs...):

- Southbank: from London Bridge to Rotherhithe. This area did not require of leverage as its proximity to the heart of the city was enough incentive for developers. A soaring demand allowed the achievement of a high level of urbanity, characterised by high density and diversity of uses. The old urban fabric has been retained and retrofitted so as to incorporate new tertiary and alternative types of residence, such as loft accommodation in old industrial warehouses. The preservation of the industrial heritage and strategic facilities (Design Museum, Hays Galleria and the City Hall of the Greater London Authority) confers it a distinctive character that converted this area in one of the preferred locations in East London.

- Surrey Docks. Most of the old docks have been filled and the industrial pre-existences have been swept away. The result is the sequence of isolated self-referred enclaves that is so common around Docklands. The suburban character is emphasized by a large shopping centre with vast parking lots that has been located close to old Canada Dock. The urban life of minimum but the area has plenty of parkland, including a ecological corridor that connects the northern riverbank to Greenland Dock, which now accommodates a

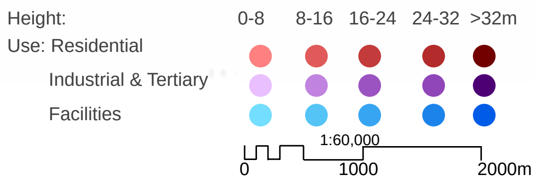


Fig.8-34 Land use and building height in 1981 (top) and 2012 (bottom)

medium rise development around the former basin designed by Conran Roche.

- Greenwich. The whole place is characterized by the presence of Christopher Wren's baroque Hospital, which now hosts a number of facilities, including the Naval Royal College and the National Maritime Museum. The historic monuments and the adjacent Observatory ensure the affluence of many visitors that generate complementary activities in a vibrant urban environment. However, little of this can be claimed a result of Docklands regeneration, although a subway connects Greenwich peer with the Island Gardens at the Isle of Dogs and the view of Canary Wharf from the top of Greenwich park is one of the most iconic images of contemporary London.

- Millennium peninsula. the Gas Works that occupied most of the peninsula have been replaced by facilities of regional and even global scale, as it is the case of the Millennium Dome (now called O2 arena). Despite the plans to transform the area into a mixed urban centrality and the improved access, with a Jubilee line station and now a cable car to the Royal Docks, its interest is limited to the occurrence of special events. In the southern part, there is one of the few residential developments that has been completed, the Millennium Village, which is an autonomous unit, with its own school and community centre. It was design by Ralph Erskine and partners as a model of sustainable development in a neo-vernacular style.

- Woolwich. This area, which emerged around the former Royal Arsenal and Shipyard, has evolved in an independent way. Its excentric location and a consolidated urban fabric

Fig.8-35 Demolished buildings during the period 1981-2012 (in colours)

Fig.8-36 Existing buildings in 1981 that have remained until 2012 (in colours)

Fig.8-37 New constructions during the period 1981-2012 (in colours)

Overlapping of current and historic urban structure

Historic Docklands 1945

Contemporary Docklands 2012

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0 50 100 200m

Fig.8-38 Barkantine, Isle of Dogs

Fig.8-39 Canary Wharf, Isle of Dogs

Fig.8-40 Chapel House Conservation Area and Mudchute Park, Isle of Dogs

when regeneration started made it a low priority target.

- Royal Docks. They have been subject of numerous plans, some of which were only partially accomplished. Overall, transformation is still ongoing, as low quality industrial estates are currently scattered along the river bank. Low dense residential clusters are connected by the DRL line but they are otherwise detached from any urban centrality. The abundant space has attracted large scale facilities around the former docks, such as the Excel Exhibition and Conference Centre, the City Airport or the East London University. Urbanization advances slowly from West to East, but the general impression is of an isolated place.

- From Limehouse to Saint Katharine's Dock. Being at an arm's length to the City was, likewise in the Tower Bridge and Rotherhithe, a strong incentive. This area is characterised by the mixture of the old fabric and newer interstitial developments, particularly concentrated around the disused basins of Limehouse, Shadwell and Saint Katharine's. The latter was, as aforementioned, a pioneer experiment for the regeneration of Docklands, as it was based on new tertiary activities and luxury flats.

- The Isle of Dogs. The spatial transformation acquired a maximal expression in of the Isle of Dogs, where only around a dozen industrial buildings, three churches and ten residential estates have survived the "tabula rasa" approach taken by the LDDC. The industrial architecture is only portrayed by the Museum of Docklands, in the northwest corner, and a couple other sheds that have been refurbished as loft apartments in the southern part of the peninsula. Notwithstanding the administrative subdivisions, three distinctive areas can be defined in the Isle of Dogs:

- The riverfront perimeter. Small industries were replaced by private, often gated, residential estates. Apartment blocks in enclosed clusters with common private areas are the prevailing typology. River access was restricted by some of these developments, a situation that was partly reversed by

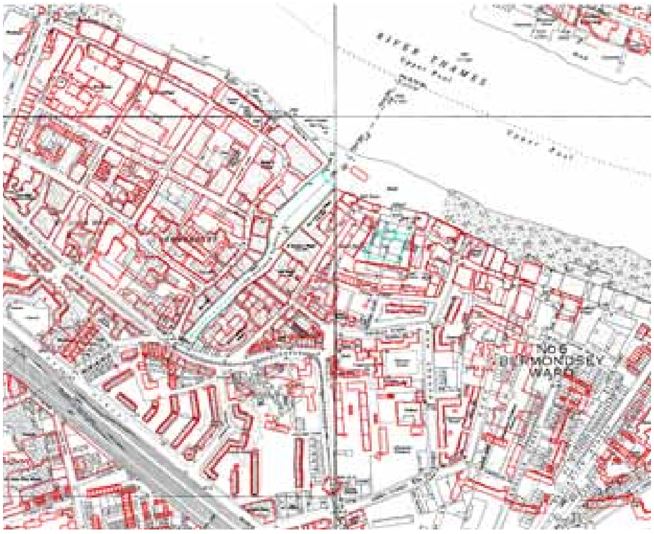

Fig.8-41 Berdmondsey

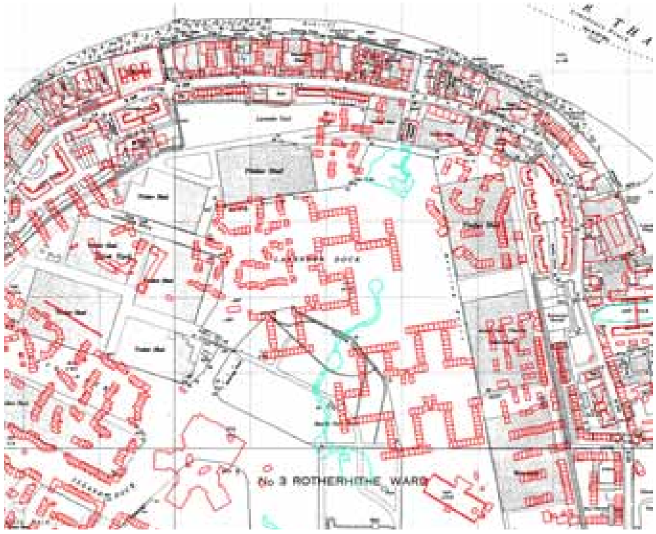

Fig.8-44 Surrey Docks

Fig.8-42 New residential estates in Blackwall, at former East India Dock

Fig.8-45 Brittania Village at Royal Docks

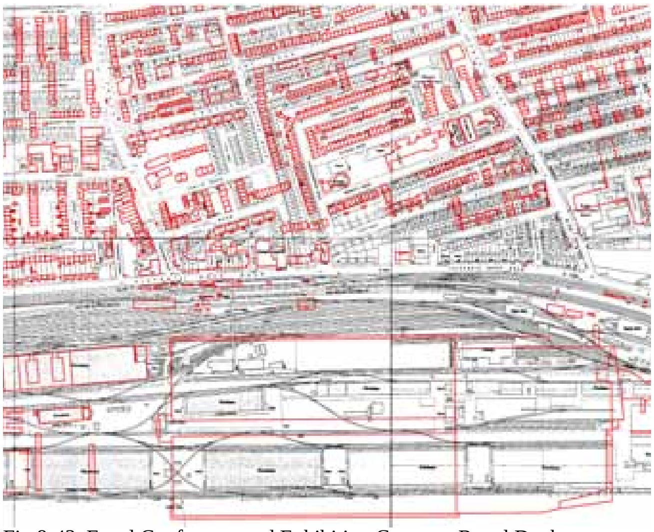

Fig.8-43 Excel Conference and Exhibition Center at Royal Docks

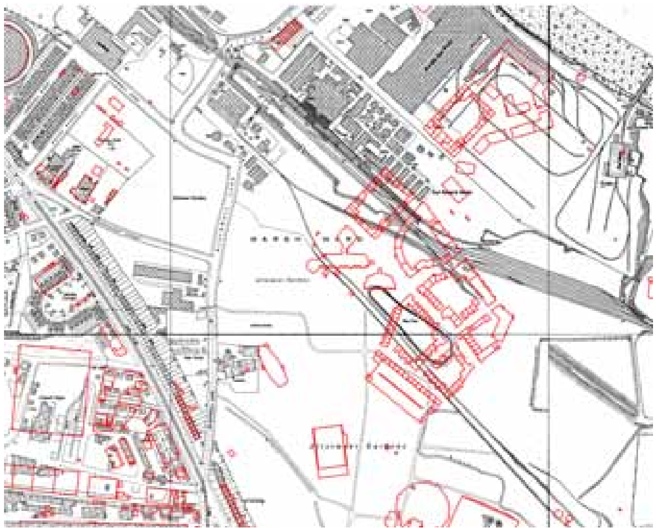

Fig.8-46 Millenium Village at Millenium Peninsula


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Fig.8-47 Architecture of the north bank of Docklands, from the Thames (see image position below)


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Fig.8-48 Inside Docklands (see image position below)


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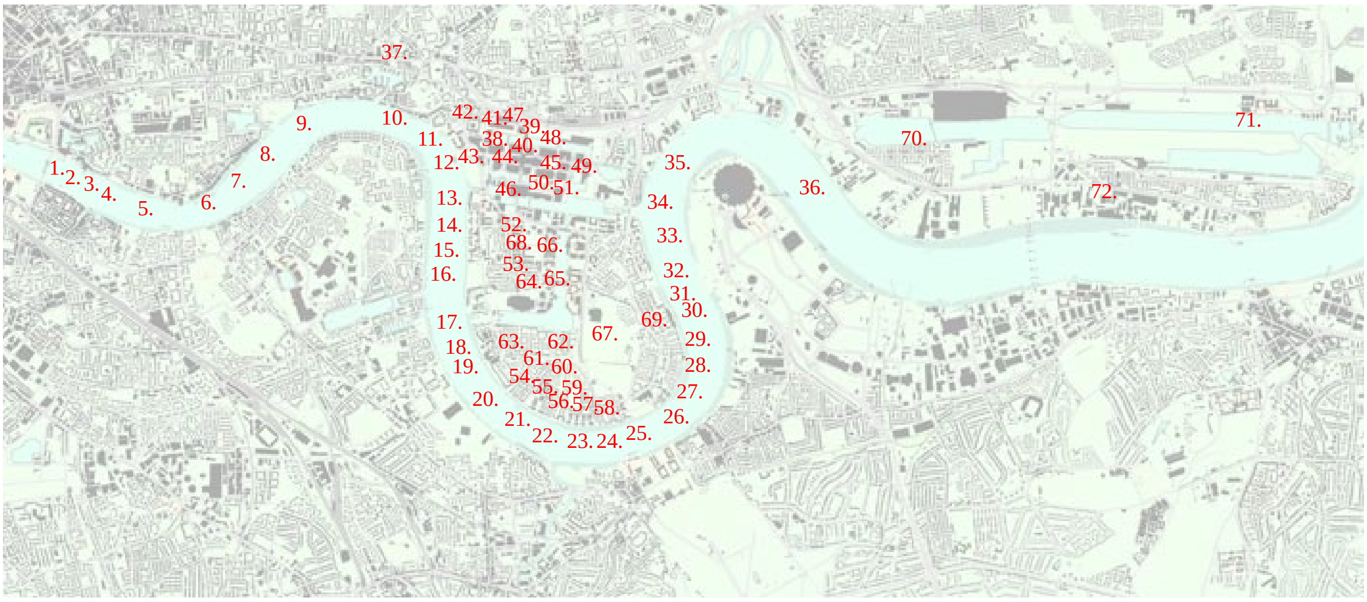

Fig.8-49 Contemporary Docklands and image positions

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the creation of a pedestrian pathway along the Thames from the Tower to Island Gardens. Architectural styles are diverse, ranging from postmodernism (e.g. Cascades) to picturesque neo-vernacular (e.g. Compass Point, Amsterdam Road) and interpretations of industrial (e.g. Cyclops Wharf) and nautical themes (e.g. Anchorage). Among all the residential schemes, only Cumberland Mill has an interest as typological exploration.

- The Enterprise Zone. It included the areas around West India and Millwall Docks (fig. 8-16). Here it would be necessary to differentiate between Canary Wharf and Millwall. The former has been sufficiently described in previous sections as a manufactured cityscape and a banal repetition of the archetypal business design model. Millwall is another version of a similar concept although with a greater mixture of scales and uses, from a small commercial gallery at Glengall Bridge to the large facilities at Westferry and the residential developments to the south of the Dock (Clippers Way and Timber Wharves Village).

-The rest of the Isle, this is, the areas that are not adjacent to water, are arranged to the inland part of Manchester (to the East) and Westferry (to the West) roads. Most of the pre-existing structures that have remained throughout the process are concentrated in these zones. There are three distinctive zones: Cubitt Town, to the east, which is predominantly composed of council estates from the 1960s (Kensol house, Samuda or St. John's Estates), Mudchute Park, to the south, with the adjacent conservation area at Chapel House and, finally, Barkantine, to the East, an autonomous council estate from the late seventies.

8.3.1. Densification at Docklands

The main reason to select Docklands as case study was to analyze a densification process in an inner location. It is therefore necessary to point out the dimensions of the resulting built environment after the regeneration. This could be done by the observation of figure 8-34 as it includes information of the building's volume before and after the process. It can be, moreover, complemented by looking at the specific figures compiled in figure 8-53, which shows how the floor space doubled and the population became four times as large. Arguably, seizing the opportunity of inner urban growth prevents further sprawl. The inhabitants of these regenerated neighbourhoods will be based to a few miles distance from the main employment centres in London at the City and West End. Furthermore, jobs density was also enhanced by the new centrality created at Canary Wharf thus providing a third hub in central London.

The environmental effects of densification will be explored in chapter 11. Nevertheless an spatial analytic technique was applied in order to visualize the urban intensification in a synthetic parameter that combines density with connectivity and a notion of centrality. "Reach" is a quantitative measure that accounts for interaction opportunities at any given location. More specifically, it "captures how many surrounding buildings each building reaches within a given Search Radius on the network"[126]. A computational tool, Urban Network Analysis, has been developed by the SUTD/MIT City Form Lab[127] that allows calculating and mapping "Reach" and other morphological

126 Sevtsuk, 2013

127 cityform.mit.edu/projects/urban-network-analysis.html [last accessed 26.11.2013]

Fig.8-50 Docklands 1981. Reach Radius:1,000m Building weight: Volume

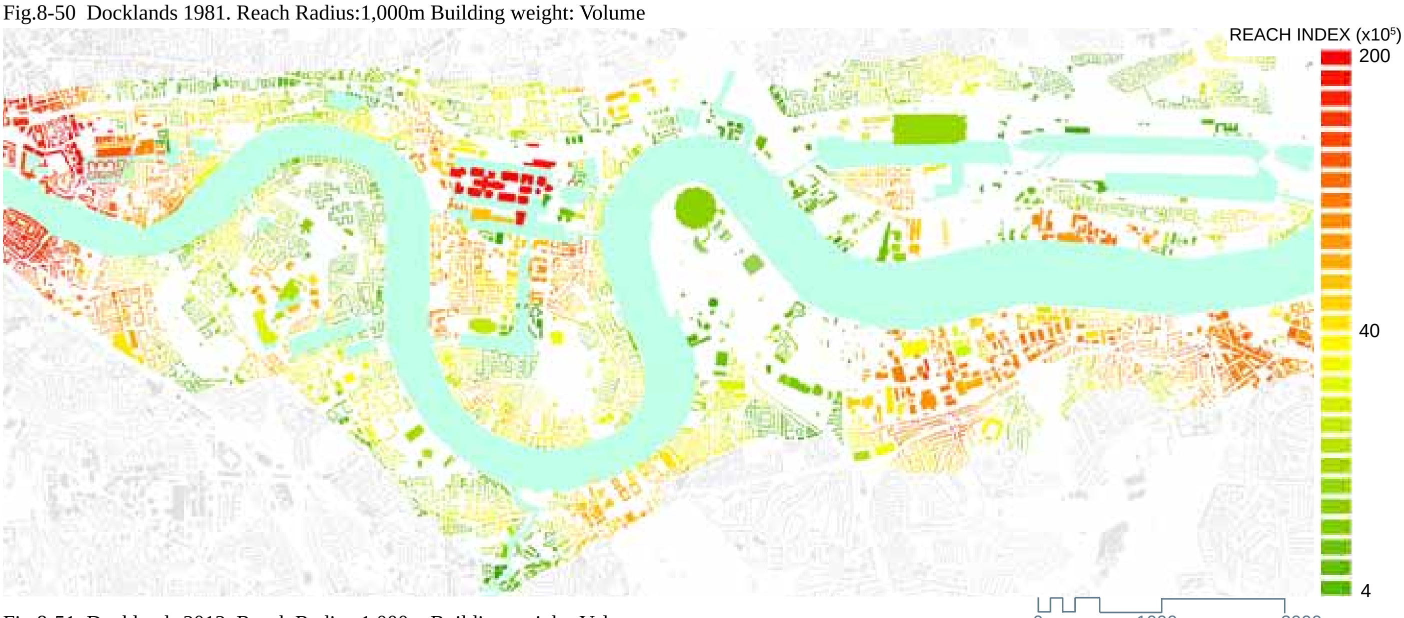

Fig.8-51 Docklands 2012. Reach Radius:1,000m Building weight: Volume

Fig.8-52 Central London 2012. Reach. Radius:1,000m Building weight: Number of building units

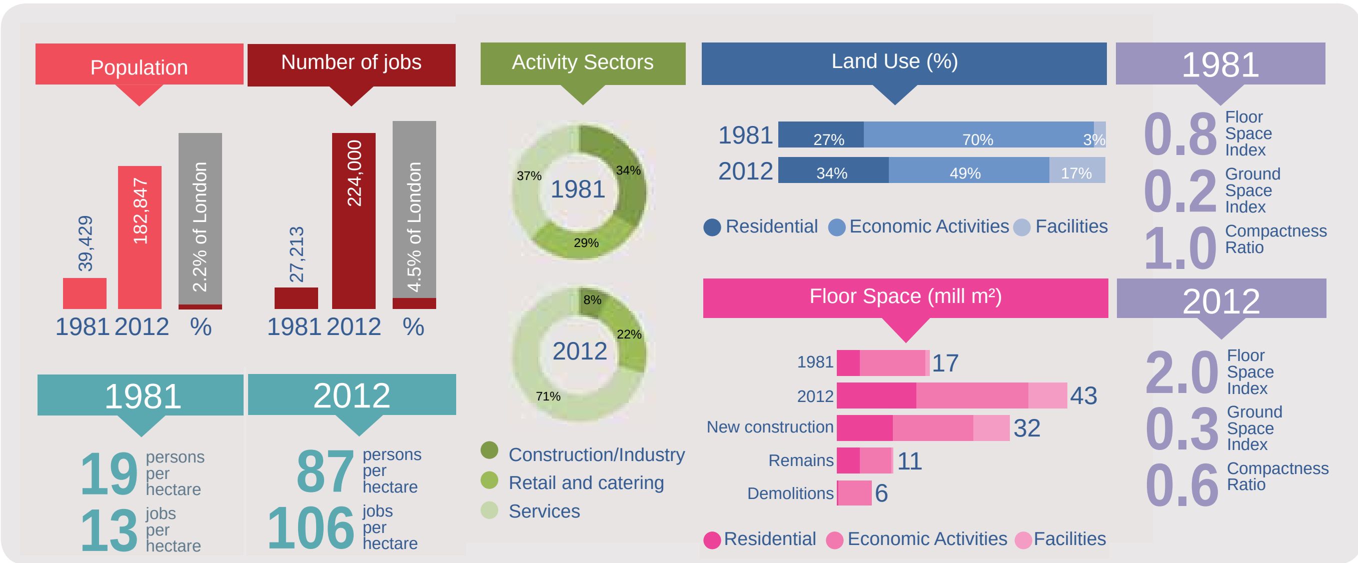

Fig.8-53 Summary statistic of London Docklands transformation

parameters in a GIS platform. The tool can be calibrated to weight buildings according to their size, which, in this case, is defined by their total floor area. In this way, the analysis will emphasize density and centrality over diversity as the number of units that within the given reach are undermined.

A first analysis was undertaken under these conditions, to compare the built environment in Docklands before (1981) and after (2012) the regeneration (figs. 8-50 and 8-51). The number of destinations was calibrated by their floor area and the reach was set to 1,000 meters, thus defining a walkable distance measured on the street network. The new centrality in Canary Wharf becomes apparent as so does the intensification in the areas closer to the City, both in the north and south banks. In contrast, the large facilities on Millennium peninsula and the Royal Docks show low values, which are explained by their isolated location and having only few neighbouring buildings within the defined distance of 1,000m.

The second analysis compared contemporary Docklands with other areas in London, such as the City or the West End. In this case buildings were not weighted and the "reach" parameter was only computed as the number of different building units that are reachable from each other building along the street network within 1,000m distance. In this comparison, the new cityscape at Docklands has not yet achieved the same spatial complexity as in the areas of Westminster and the West End, where the combination of high density and a fine plot subdivision offers, in principle, greater accessibility and interaction opportunities.

Finally, the densification figures in Docklands have been related to the historical evolution of London. Despite the small proportion that the area represents, in terms of size and population respect to the city as a whole (around 3%), the intervention represents a change of trend. The strong decentralization started after the WWII has been only reversed at the turn of the century, when inner London's population grew faster than the outer boroughs for the first time since the 19th century. It may be unfeasible and undesirable to return to density values of the 17th century. However, the example in Docklands, together with this graph, show the scope for urban growth within the current fabric, by intensifying underused interstices and preventing further expansion.

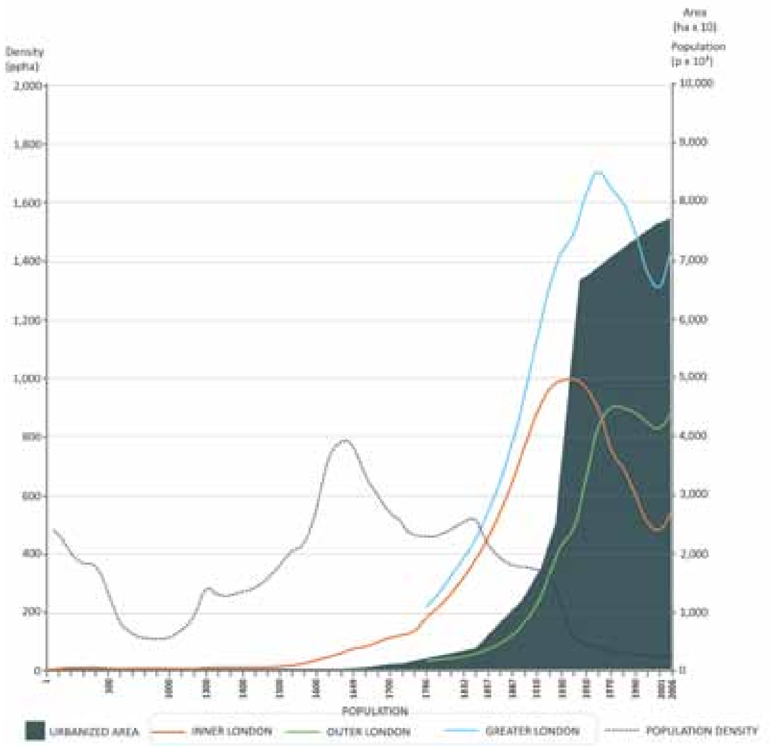

Fig.8-54 Historic evolution of Density, Population and Urbanized Area in Central and Greater London

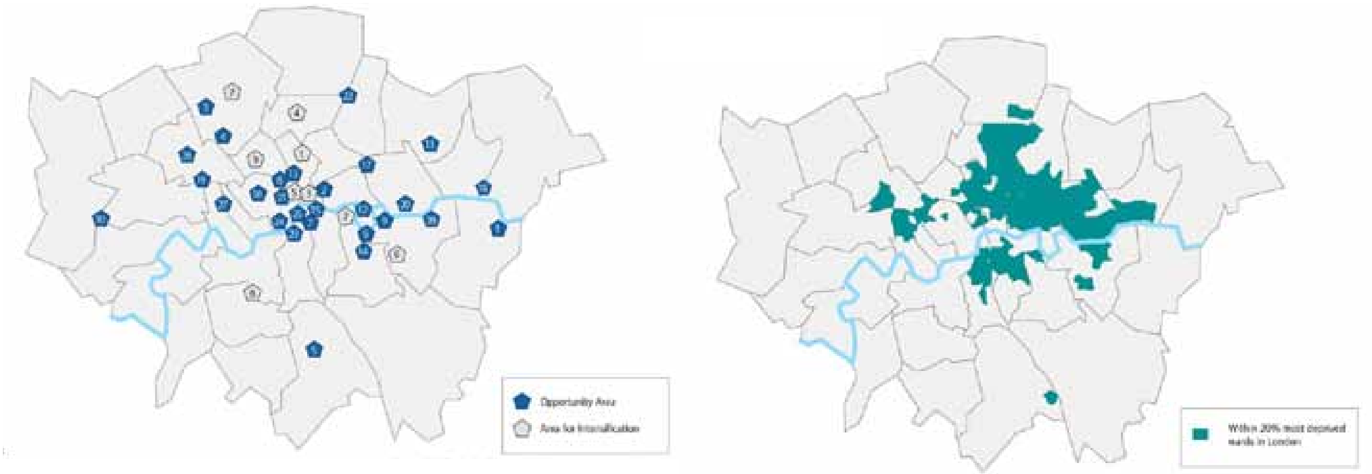

Fig.8-55 Opportunity Areas for Intensification (left) and Areas for Regeneration according to the London Plan 2004 (GLA)

8.4. Future plans: Thames Gateway

The former Docklands were no longer an homogenous area of decay and obsolescence. The regeneration process followed a different pace at each zone. The Isle of Dogs was, at the beginning of this period, a consolidated financial centre with over 90,000 jobs. Property developers were keen on investing in new schemes without the need of incentives. Other areas, such as the Royal Docks or the Lower Lea valley were still at a more seminal state. Undervalued industries and abandoned sites occupied most of the land. A new term would be coined to refer to these and other riverside areas to the east of the city that would allow further expansion of London: The Thames Gateway.

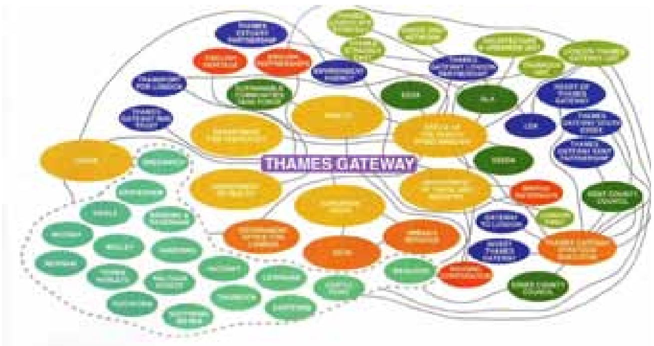

Fig.8-56 The Governance problem at Thames Gateway as illustrated by Farrell & Partners (source: Aminosssehe , 2004)

The idea of exploring the Thames low estuary had been first explored in 1991, when the conservative government commissioned an study on the East London Corridor. The conclusions from that study led to the creation of the Thames Gateway Task Force in 1995 and the Thames Gateway Planning Framework. The target was to provide space for new jobs and homes in a sustainable way. The initial years, the activity in the Thames Gateway was slow. The complexity derived from ownership, governance[128] and geography (almost the whole area is within Thames' floodplain) prevented any substantial action to take place. In 2004 the Local Government Planning & Land Act of 1980 was retrieved to establish two new Urban Development Corporations: the London Thames Gateway Development Corporation (LTGDC) and the Thurrock Thames Gateway Development Corporation (TTGDC) near Tilbury port. They would coordinate the regeneration of their ascribed zones for an expected period of ten years. Unlike the LDDC, these corporations had not only to coexist but to collaborate with an amalgam of national, local, private and public bodies, which strengthened the problem of governance and, according to some authors, it undermined the pursue of a common strategy[129]. This was, however, in line with the new labour belief on partnerships and networked governance. The UDCs were no longer mechanism to force an specific approach to regeneration while bypassing local authorities. They rather acted as facilitators, among intermixed agencies at various scales. At present time (2013), both corporations have ceased their operations with a different level of achievement. Whereas the LTGDC took advantage of the 2012 Olympics, whose main venues (Stadium, Olympic Village) were located at Stratford, the regeneration in Thurrock was not nearly as intense as it had been in Docklands. Nevertheless, the Thames Gateway is still considered an strategic corridor for London's future growth, as stated on the London Plan 2011[130]. Several key projects have been completed or secured in the Thames Gateway area in recent years:

128 See Brownill et al, 2007
129Richard Rogers quoted in Brownill et al 2007
130 GLA, 2011

- The Olympic Park and Olympic village, which will create a new centrality in former brownfield site on Lee riverside at Stratford.
- New regional-scale facilities such the O2 arena or the London Excel Conference Centre
- Crossrail Stations under construction will enhance the connectivity with central London and the South East region. Stratford International station was intended as an stop of the Eurostar but the operator finally rejected the idea due to possible delay in journey times[131].
- Large residential developments have been started, such as Eastern Quarry or Barking Riverside.

In 2007 Terry Farrell was appointed by the Homes and Communities Agency to create a design framework for the Thames Gateway in order to make it more attractive for investors and to raise the project's profile. He proposed the use of landscape and environmental restoration to provide continuity to what it was being perceived as piecemeal interventions. Farrell envisioned Parkland, a green continuum that was intertwined with the new communities by linear corridors and natural reserves. The natural features of the estuary, such as marshes and river-scapes, would be preserved and enhanced to transform the historical perception of the riverside from a place of utilities to a place where people wanted to live and work[132]. Farrell had been campaigning for this vision since 2001 and his work was profusely illustrated with graphics of great visual appeal. He argued that key projects that were under way had been anticipated in his earlier studies. A detailed report on those fifteen projects was collected in a later document.[133] In reality they were small interventions (over ₤60 million of investment for all of them) if they are placed in the context of the "largest regeneration project in Europe[134]".

According to critics, Thames Gateway plan reached a standstill as the eco-region idea of Farrell was as utopian as the philanthropic Garden City of the early twentieth century[135]. The new economic downturn, started in 2008, followed by double dip recession in the British economy, slowed the pace of new developments. However, housing shortage is still a problem in London and plans for housing construction are likely to be released in the short or medium term. The Gateway can be then considered as the London land reserve that will absorb the future growth of the metropolis, whenever this takes place. Unlike the regeneration in Docklands, it means a physical expansion of the urbanized territory, thus contradicting some of the principles about containment and density that had been set out by the Urban Task Force. To some extent, the continuous growth that was proposed as a sustainable eco-region, and composed of environmentally friendly communities, deeply integrated in the natural landscape, contrasts with the model of inner city regeneration which was followed in Docklands. It also collides with the urban manifesto advocated by the new Labour.

The state of the area formerly managed by the LDDC could be considered as fully integrated in London's urban structure, both physically and functionally. The transport capacity had been substantially increased with the Jubilee line extension and the DLR improvements (five new branches), while the Crossrail line is due for completion between 2018 and 2019[136] and the City airport connects with the continent. Canary Wharf became a main working centre and the number of jobs has continuously increased in the last years. The reliance on the financial sector, as the base of employment, has created and overexposure to economic crisis. It became apparent between April and October of 2008, when the most important tenants of Canary Wharf were hit by the credit crunch. Citigroup, HSBC or Bank of American axed thousands of jobs while Lehman Brothers' collapse meant a loss of 4,000 jobs from its offices at Docklands[137]. However, the strength of the address enabled a quick recovery as new firms started to replace the falling branches. JP Morgan signed a deal to move to Canary Wharf already in November 2008[138] . When that move was executed, in 2012, the new "citadel of finance" officially overtook the City as "the bigger employer of bankers in Europe"[139] (44,500 bankers in Canary Wharf against 43,300 in the City). The resilience against economic turbulences is still weak as the employment has concentrated only in six firms (HSBC, Barclays, Credit Suisse Investment, JPMorgan, Citigroup and Morgan Stanley)[140] and the percentage working in banking is still around 50% (44,500 out of 90,000 workers). About a quarter of the working population lives now at the East End and only 10% are living at Tower Hamlets borough[141]. That same year the managing company of the estate purchased the right to develop Wood Wharf, to expand the complex to the East. The masterplan was designed by Farrell & partners, replacing a project by Richard Rogers. With this new development, the Canary Wharf group aims to diversify the portfolio on the area, targeting new sectors in office accommodation (creative media, technology and telecommunications) as well as to increase the amenities and residential offer. It is indicative of the expectation that the zone still generates, as there is little sign of a fall in the flow of firms coming from other parts of London or abroad. The appeal is however greater

131 BBC, 2010
132 Terry Farrell & Partners, 2010
133 Mayor of London, 2010
134 DCLG, 2007
135 Baillieu, A. (2007) Gateway reaches crisis Point. Article at BD Magazine/ BDOnlie http://www.bdonline.co.uk/comment/gateway-reaches-crisis-point/3101268.article [last accessed 24.03.2013]

136 www.crossrail.co.uk/ [last accessed 24.03.2013]
137Prynn, 2008
138 Ruddick, 2008
139 Jenkins & Hammond, 2012
140 Ibid
141 Pickford, 2012

Fig.8-57 Thames Gateway Parklands (Terry Farrel & Partners, 2010)

for companies than for workers, who reportedly state their preference for the beehive-like dynamic diversity of the City than for the sterilized urban environment of the Wharf:

"There is life in Canary Wharf but it's pretty sterile life"

"There is a degree on inhumanity in Canary Wharf. One of the joys if the City is the mix of streets, the different people, the independent shops" [142]

The residential market was at least as active as the commercial and the trend has gone decidedly towards greater density and a polarized social structure. The building activity is concentrated in the northern part of the Isle of Dogs, Millennium peninsula and Surrey Docks while in the Royals only few scattered developments have been completed.

Each area presents a different character:

- In the Isle of Dogs a number of residential towers are under construction. Two have been built out in recent years (The Landmark, Pan Peninsula) while others have been already granted planning permission (Baltimore Wharf, 40 Marsh Wall, Dollar Bay, City Pride...[143]). Large scale schemes prevail around the Canary Wharf while the riverside has been completely filled with gated communities. Each development is a self-contained unity with little relation with its surroundings
- The riverfront at Surrey Docks is also composed of gated housing developments of varied scale, from medium to moderately high density. The former docks have been used as marinas, new squares that enable space between blocks.
- The Royal Docks are characterized by suburban-like communities to the south side of the basins and large facilities to the north, while the riverfront remains occupied by low quality industries. Only at both extremes, east and west, of the old Docks, recent developments have broken with the suburban types to erect accommodation of more urban character.

142 Two senior bankers quoted at Jenkins, P. & Hammond, E. (2012)
143 Tower Hamlets, 2013

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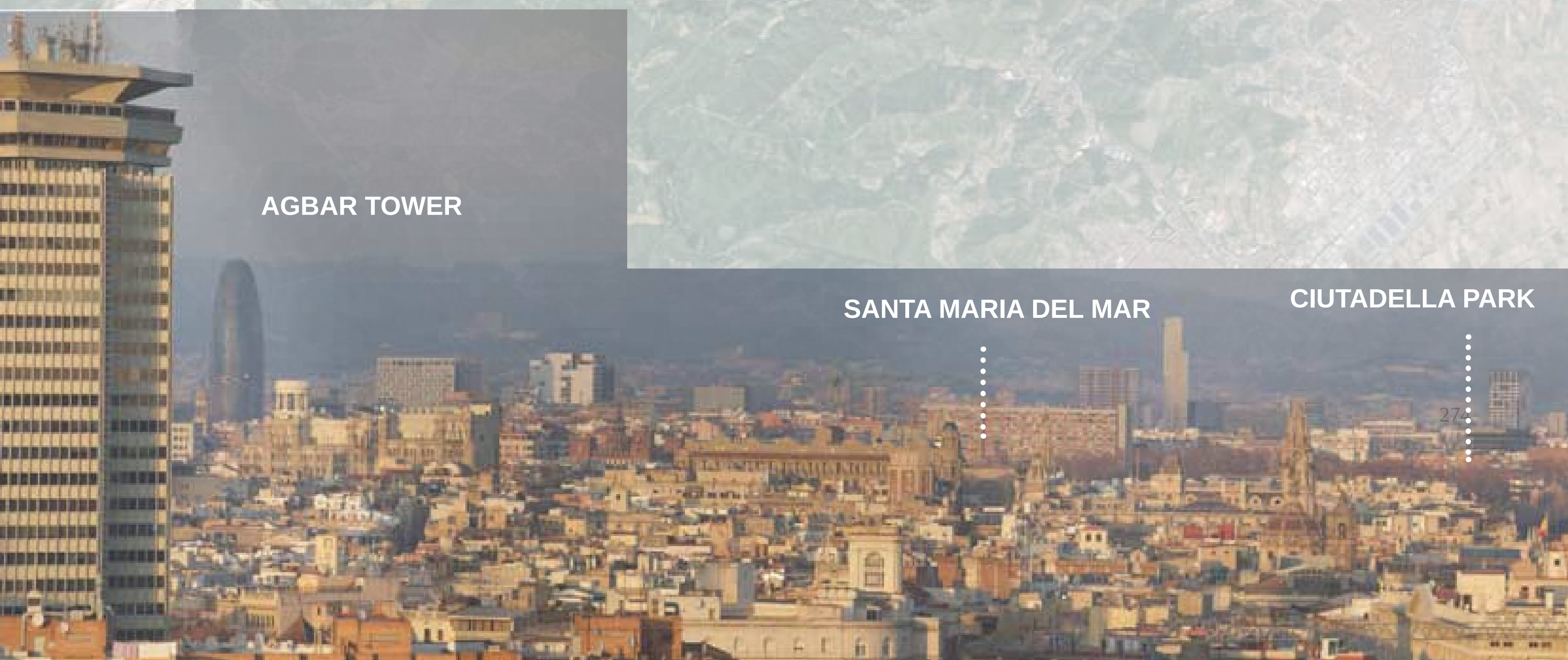
VIEW FROM MONTJUÏC TOWARDS NE (Collserola hills in the background)

VIEW FROM MONTJUÏC TOWARDS NW (Port Vell and the historic quarters)

SAGRADA FAMILIA

CATHEDRAL

AGBAR TOWER



CHAPTER 9

A COMPACT CITY PARADIGM: BARCELONA

The view from Montjuïc

Barcelona is a quintessential Mediterranean city: dense, compact, lively and a bit chaotic. It emerged at the base of a promontory, Montjüic, whose hillside offers a perfect outlook to understand the contemporary city as the product of historical evolution. From this position, it is observed as a cross section trough the shortest axis (NW-SE). Urbanization has apparently spread over the last available piece of territory whose slope was suitable for construction. The Collserola Mountains, to the northwest, and the Mediterranean Sea, to the southeast, have framed the urban expansion and compose a continuous background for urban life. Despite the presence of the city, it is possible to infer the underlying topographic layer. A gently sloping, though predominantly flat, terrain stretches from the sea to the base of Collserola. Several streams used to traverse the plain, but their traces can be hardly distinguished. Only the statue of Cristobal Columbus highlights the position of the Rambla, the natural drain of the area. Two rivers, nearly perpendicular to the sea, delimited the city to northeast and southwest respectively. Besós River can be identified, at the background of this panorama, by the silhouette of three slender chimneys, which mark the position of Besós Power Station. Llobregat River is located behind the observer, to the south of Montjüic, where a large logistics area has been established on the formerly agricultural estuary.

The observation of the urban fabric from this position provides a glimpse of the city's history. To the right, the old port, whose grounds were reclaimed from the sea since the 16th century. It has now been converted into a fashionable marina, filled with yachts and surrounded by landscaped promenades. Behind the port, La Barceloneta district can be identified. This is a residential quarter built in the 18th century to compensate the loss of homes caused by the construction of the Citadel (Ciutadella). The fortress has been now transformed into a park, whose tree canopy is barely distinguishable from this outlook, right to the left of La Barceloneta. The Citadel marked the northern limit of the Gothic Barcelona, just as the Dressanes (former shipyards, now a museum it is the low rise construction with a long tiled roof at the base of Columbus monument) was the southern edge. With these two references, it would be possible to trace two virtual horizontal lines towards the hinterland. These lines would intersect with the three chimneys of a former Electric Power Station (not Besós). At that point, a vertical line could be drawn to connect both lines thus terminating virtual polygon that would contain the urbanized area of Barcelona from medieval times to the mid 19th century.

Fig.9-1 View of the city from Montjüic. In colour, the boundaries of the medieval city

Fig.9-2 The same view as it was in the 15th century. Engraving by Vermeyen (reproduced from Ajuntament de Barcelona)

Fig.9-3 This panorama of Barcelona was broadcasted to a worldwide audience during the 1992 Olympics as it corresponds to the celebrated venue for the diving contest. The recent FINA 2013 World Championships used the same location (photo: Manu Fernández/AP reproduced from Financial Times)

Fig.9-4 View of Barcelona from Parc Güell. The continuous roofscape follows the gentle slope of the terrain towards the sea. Only the towers at the Olympic Port and Sagrada Familia interrupt the skyline

Zooming into the historic precinct, El Raval district is at the forefront. This was the stretch of land that remained between the Rambla and the outer wall. It was used for agriculture and to locate large ecclesiastic premises until the 19th century, when emerging industries (cotton, manufacture of printed calicoes[1]) took over. In the 1980s this was one of the most overcrowded and deprived districts of the city. The regeneration that was undertaken involved large scale demolitions to open boulevards and to accommodate modern buildings and cultural facilities. A 110 meters tower stands out at the middle of the view as a strange element for an historic city. It is an office building from the seventies without any architectural interest, other than remainder of an unfortunate period of overdevelopment and speculation. Had that eyesore not been there, some of the most important monuments of the medieval city could be better appreciated in this vista. Despite the densification of the so called Gothic quarter, several bell towers and pinnacles can be identified among the roofs. To the left, the octagonal dome of Saint Agustin, a former convent from the 18th century. Next to it, it is Santa María del Pi, a Gothic temple from the 14th century, and, between this and the office tower, the Cathedral of Barcelona. The Cathedral was built between the 13th and 14th centuries, although the dome and the main façade were not completed until the early 20th century, based on original designs. There is another church, in the old city, which overpasses the cathedral for its great symbolism. Santa María del Mar is a Gothic church, from the same period (13th century), located at the Ribera district. Its rose window (replaced in the 15th century after an earthquake had destroyed it) can be noticed between the office tower and Columbus monument. What is remarkable in Santa Maria del Mar, apart from its architectural features, was the involvement of all guilds in the maritime district (Ribera). They contributed with their money and labour to erect a majestic sanctuary to Saint Mary.

For most of its history, Barcelona remained as a walled city. Only in the mid 19th century, when population density reached over 85,000people/Km² (850 ppha)[2] within the medieval enclosure, was the city released from its stoned straitjacket. The colonization of the plain, beyond the walls, was undertaken in two main ways: the organic growth of existing suburban towns (Sarriá, Sant Gervasi or Horta) and a remarkable enlargement project (Eixample) devised by the engineer Ildefonso Cerdà. The characteristic Eixample's grid is perhaps one of the most renown and studied forms in the history of urbanism. Most of the buildings were, therefore, built from the 19th century onwards. However, many of them have already become architectural landmarks. The Sagrada Familia's basilica is another icon of Barcelona. Although it is still unfinished, Gaudí's most notable design has dominated the Eixample's skyline for almost seventy years. New skyscrapers have populated the city's profile since the 1992 Olympics, a key event in the modern history of Barcelona that left a substantial imprint in the urban structure. Two towers (Arts Hotel and Mapfre Tower) that can be distinguished behind Barceloneta were part of the physical residue from that event. Further north, a cluster of tall buildings marks the convergence of the Diagonal Avenue, the city's main thoroughfare, with the sea. The opening of the Diagonal was a long delayed project which became a reality at the end of the 20th century. The execution of this project was associated with an international event that aimed to replicate the successful strategy of the Olympics, combining an international fair (Forum de las Culturas) with urban regeneration. The Diagonal Avenue is a straight line that slashes the orthogonal grid obliquely. Representative and institutional buildings concentrate at both sides of the avenue, which gives them great visibility. In 2005, a new addition to Barcelona's skyline was completed at the junction of Diagonal with other two other important avenues (Gran Vía and Meridiana), called Les Glòries. The tower was designed by Jean Nouvel for the Barcelona's water company (Agbar). Its characteristic silhouette can be distinguished to right of the brutalist office tower. It has become a new symbol of the city and it highlights the position of the most recent urban experiment in Barcelona, the transformation of the former industrial area at Poblenou into a fashionable, innovative and creative district: the 22@.

1 Venteo, 2013
2 Busquets, 2004 p.122

BARCINO

Urbanized Area:
11 ha

Population:
2,500

Density:
227 ppha

Fig.9-6 Current characteristic urban form on old Barcino Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

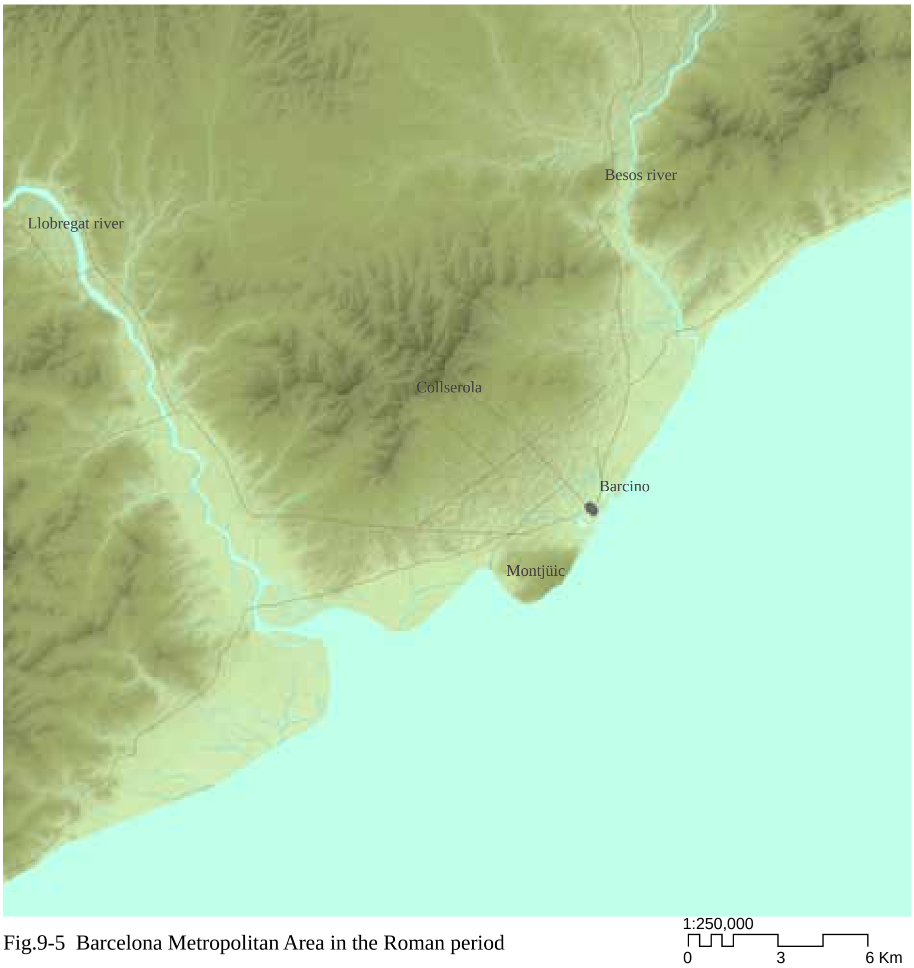


Fig.9-5 Barcelona Metropolitan Area in the Roman period

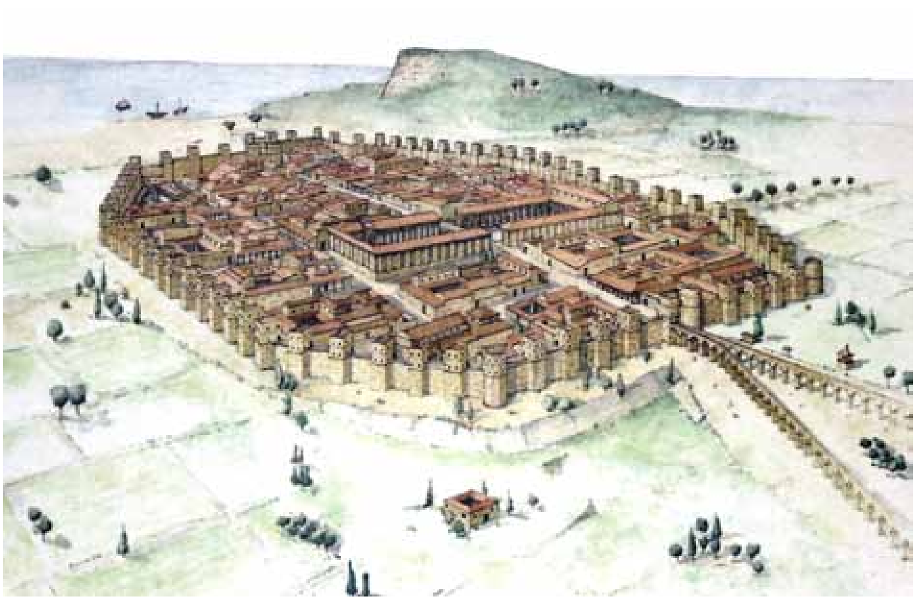


Fig.9-7 Recreation of Barcino (source: Museu d´’Historia de Barcelona, 2012)

9.1 The origins of a compact city: the Roman foundation

An insightful observer would notice a subtle elevation in the terrain around the Cathedral, slightly towards the sea. That was, in fact, Mons Taber, a small hill where the first permanent settlement was established between years 15 and 13 BC by the Romans[3]. Romans had arrived to the Iberian Peninsula during the Punic Wars against the Carthaginians. In the year 218 BC General Cneo Cornelio Escipión arrived to Emporion (Empúries) to prevent the advance of Anibal Barca's army. After some initial defeats, the Romans prevailed and started the colonization of the peninsula. The Romanization process implied the conservation of strategic villages and the foundation of a network of new towns, which were to be mainly inhabited by Roman colonists, to secure the dominium over the territory and its resources[4]. Tarraco, where Cneo Escipión had established a fort, was recognized as a colony in 45 BC .It became the capital of Tarraconensis, the Roman province, in 26 BC[5]. Several small towns were then founded to defend the area: Ilerda (Lleida), Baetulo (Badalona) or Gerunda (Girona). The predominantly rural Iberian civilization was being replaced by the urban Empire and most of the cities founded in this period remained inhabited for over 2,000 years. The foundation of Barcelona responded to the systematic colonization and a period of great urban expansion, encouraged by Emperor Augusto. The original settlement was founded between the years 15-13 BC, on the top of that small Mount Taber. It received the name of Iulia Augusta Paterna Faventina Barcino, although in most texts is called Barcino.

As in the case of Londinum, topography and drainage system were determinant factors in the seminal urban form. The Taber's elevated position allowed a good drainage and visibility over the large plain. It was surrounded by two brooks born in Collserolla (Sant Miquel and Torrent de l'Olla[6]), which put a limit to the urban extension and offered further defensive and other practical advantages. Barcino was a medium sized city for the standards of the Empire, it barely had 5,000 inhabitants within the 11 hectares of the walled precinct. The wall is the most distinctive Roman remains for it can be clearly distinguished in the current urban structure. The form of Barcino was defined and determined by its wall, perpetuating the initial perimeter during the whole Roman period. The initial construction was erected in the 1st century. The aimed rectangular shape had to be adapted to the topographic conditions so that it resulted into a bevel-edged octagon, with orthogonal axes sized 412 by 282 meters. In the 4th century, the wall was reinforced due to the threat from German invasions. The defense of Barcino could not rely on its scarce military power. An external layer of stone and the concrete infill, a mixture of mortar and rocks, were used to build one of the strongest defensive structures of the Empire. The resulting wall was over 10m high and 4m thick in the flat panes, which were flanked by defensive towers, 78 in total, 20m high by 6 m deep[7]. There were four gates, aligned with the main streets of the city: Cardus and Decumanus.

Barcino's urban layout followed the established procedure of Roman new town foundation, which was inherited from military camps. Surveyors were key members of military campaigns and it was customary they'd set up a *gnoma* in the centre of the camp[8]. The *gnoma* was rudimentary transit, devised by the Egyptians, which allowed the sighting of a main direction and its orthogonal in the field. The foundation of a new town consisted on three simple steps:

- First, the *Decumanus Maximus* would take the orientation of the sunrise at the foundation day.
- Then, the *Cardus Maximus* was traced in the orthogonal direction.
- Finally, a grid parallel to the two main axes would fill the four quadrants.

The junction between *Cardus* and *Decumanus* was the place where public activities concentrated: the Forum. Barcino's forum was located at the current Saint Jaume Square, the current seat of the Municipal and Regional Government. The grid layout formed blocks of around 50 by 50 m, which were occupied by public premises (e.g.baths) industries (e.g. *tabernae*, *garum* factories...) and the two predominant residential types: the *domus* (large introverted houses of the wealthy families) and the *insulae* (multistoried housing block for the poorer classes).

Roman cities consisted not only on the urban center but also on a designated territory. Barcino had, as many other towns, agriculture and farming as base of the economy. At the time of foundation, the *centauration*[9] was also applied to the surrounding land. As in the city, the rural land was surveyed to define two orthogonal axial roads that would determine the orientation of the agricultural fields' subdivision. The resulting cells had typically 720m per side and they were meant to contain one hundred small holdings.[10] In Barcelona, the orientation of the rural grid was slightly tilted respect to the Decumanus. It would be aligned to current Travessera de Gràcia and Torrent de l'Olla streets. The plain between Barcino and Collserola was, therefore, organized in a grid format, as anticipating Cerdà's design for the Eixample. The fields were cultivated by slaves or colonists, in order to produce a surplus for the landowner, who lived between the rural villa and the urban domus. The land was fertile and the wine production allowed an incipient commerce in Barcino.

3 Sobrequés i Callicó, 2008 p.21
4 Morris, 1979
5 Agustí, 2010
6 Sobrequés i Callicó, 2008
7 Granados i García, 1991
8 Kostof, 1991 p.126
9 The foundational procedure
10 Kostof, 1991 p.133

11thcentury

Urbanized Area:
25ha

Population:
5,000

Density:
200pphа

Fig.9-9 Current characteristic urban form around Santa María del Mar Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

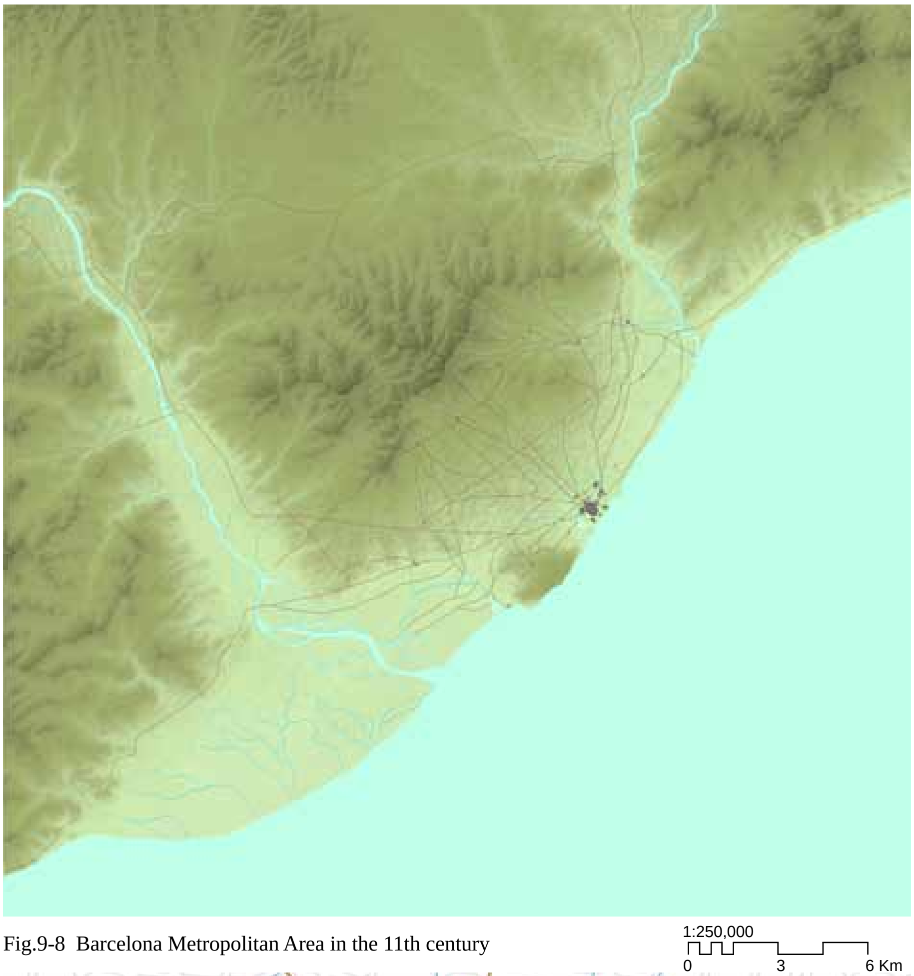


Fig.9-8 Barcelona Metropolitan Area in the 11th century

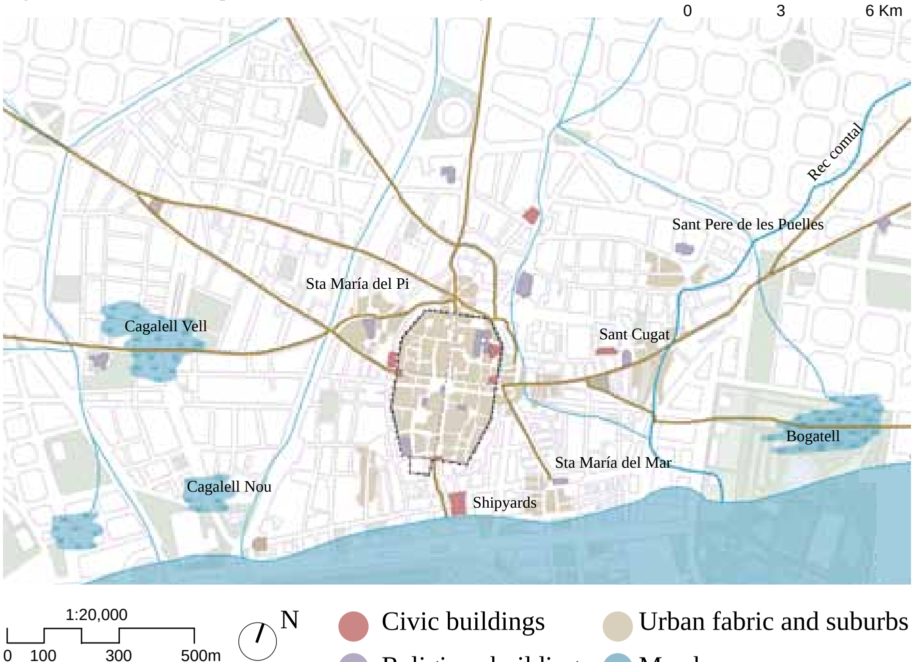


Fig.9-10 Barcelona in the 11th century overlaid on the current urban fabric. The suburbs start to colonize the main roads (source: Vinyoles, 2006)

Two aqueducts traversed the crops to supply the city with fresh water from Collserola and Besòs[11].

The trade of Barcino's products could benefit from the magnificent Roman road network, especially the Via Augusta that connected Cartago Nova with the Gallia, crossing the Iberian Mediterranea coast. Maritime trade was also important, although not to the extent of future periods. The coastline presented a totally different form as it was several hundred meters backwards respect to its present position. The Llobregat delta was an estuary and Montjüic was a peninsula. Archeological reports describe an original Iberian port to the west of Montjüic, in the Laietan settlement of Barkinos[12], which remained in operation until the 13th century[13]. When Augusto founded Barcino to the other side of Montjüic, the beach was an alternative to offload products from abroad, becoming the Roman port at the end of current Via Laietana. Evidences confirmed commercial relations between Barcino and many Mediterrean ports, from Rome to Corinth. Wine, pottery, salt and salted fish (and a side product of salted fish namely *garum*) were among the most popular products exported from the colony.

9.2 The transition towards the medieval city

The decline of the Roman Empire was hastened by the internal disputes and the pressure from the Barbarian hordes. In the 4th century, the Visigoths crossed the northern borders and sacked Rome. Five years after the siege of Rome, they entered Tarraconense in their way to Africa. Given the difficulties of further advancement, the Visigoth leader, Ataulphus established his capital in Barcelona, considered a fertile and rich land. However, this presence didn´t last long as Ataulphus was murdered and his successor moved the capital to Tolosa. Those were turbulent times for urban prosperity as the continuous social revolts and military disputes created an estate of fear and vulnerability that led to a sharp decline in trading. A ruralization process was generalized across Europe. Cities were shrinking while self-sustained rural communities were emerging. Barcelona remained an important city thanks to the demand from a military and ecclesiastical population and the strength of the Roman wall. In the 6th century Barcelona became, again, the capital of the Visigoth kingdom, being replaced by Toledo 17 years later[14]. The following centuries were dark ages for the city, with the few existing accounts related to ecclesiastical activities and wars. The Muslim invasions placed Barcelona back in a frontier position, creating a great instability and dependence of the protection of Franks. The city was occupied by Muslims from 719 to 802, when Franks regained control. Few years later, a native noble, Wifredo was proclaimed as the first Catalonian Count of Barcelona, achieving a relative independence.

The urban structure remained almost unaltered until the mid 10th century. The Roman walls had proved a valuable asset against continuous raids and there was little incentive to either surpass it or eliminate it. Inside the walls, the advent of the Christian cult required new premises. The Visigoth cathedral was erected close to the former Forum, and to the Palace of the Count of Barcelona, which was adjacent to the fortified wall. Further churches were built, such as Sant Miquel (on top of the Roman Baths), Sant Jaume (where the current square of the same name) and Sants Justo and Pastor. The city was populated but not crowded, as there were vacant lots and land for orchards and agriculture inside the walls. Those empty plots were being gradually occupied and the rectilinear streets of the centauration were being distorted and replaced by a tortuous layout.

By the mid 10th century, the walled enclosure was already too small for the pace of progress propitiated by the expansion of Christian territories to the south of Llobregat River. Barcelona was playing a key role in the commercial exchange between Al-Andalus and Europe. Despite the constant hostilities, trade throve in both directions. The flow from north to south was based on cloth, fur and iron, whereas Muslims would trade luxurious goods, such as gold, precious stones, silk or Ivory to the rest of the continent. Maritime trade was safer that terrestrial routes, which explains why the most dynamic part of the city was the old Iberian port to the south of Montjuïc. Barcelona timidly started to expand beyond the original walls. It did so, as many medieval towns, in the form of boroughs (fauburgs), churches and friaries that colonized the areas next to the gates and along the main roads. The first borough was formed next to Portal Major (Main Gate) in 966, where the former marketplace and the old castle (Castell Vell) adjacent to the road towards France (Strata Francisca[15]). A nearby junction led to Santa María del Mar (Saint Mary of the Sea) where another borough was emerging. To the west of the wall, the borough of Santa María del Pi was smaller. Further in the plain, the future municipal structure of the metropolitan area was starting in a very seminal way. The rural surroundings were being populated at the junctions of the main roads. The construction of parish churches gives account of the position and date of origin of these hamlets, which would be absorbed by the city several centuries later. Sant Andreu, Santa Eulalia de Vilapiscina, Sant Gervasi de Cassoles, Sant Julia de Montjuïc, Santa Eulalia de Provençana, Sant Vicenç de Sarriá, Sants and Sant Genìs de Agudells were all dated between the end of the 10th century and the beginning of the 11th.

11 Miró, C. & Orengo, 2010 pp.108-133
12 Asensio et al, 2009
13 Port de Barcelona, 2013
14 Sobrequés i Callico, 2008 p. 30
15 Sánchez Martínez, 1991

14th century

Urbanized Area:
74ha

Population:
30,000

Density:
405pphа

Fig.9-12 Current characteristic urban form around Plaça Sant Pere Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

1:250,000
0 3 6 Km

Fig.9-11 Barcelona Metropolitan Area in the 11th century

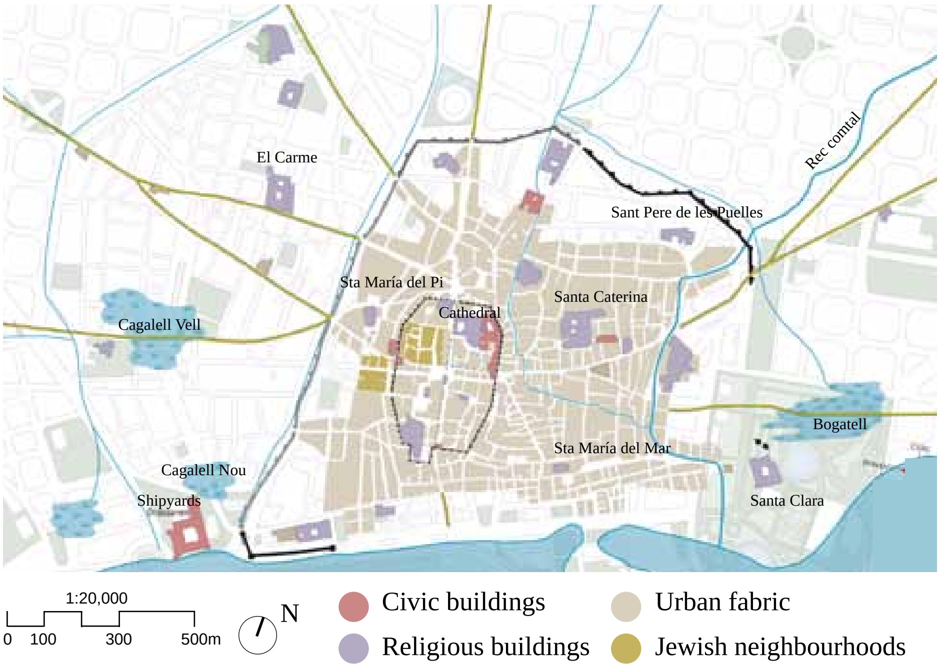


Fig.9-13 Barcelona around 14th century. The construction of the second wall has started (source:Vinyoles, 2006)

9.3 The medieval city

This period of urban prosperity was halted by an event that would become an historical landmark: the sack of the city by Al-Mansur in 985. However, the damage from the attack was limited and, instead of a recession, it triggered a period of great expansion, both political and economical. The passive attitude of the Franks during Al-Mansur's raid created a distrust against them that would eventually lead to the formal independence of Barcelona and its territory (County of Barcelona). The dominion of the Counts would advance generation after generation, either by purchasing new territories (Carcassonne, Rasés), by marriages or by military conquests. If during the 11th century, the emphasis was on the area beyond the Pyrenees, on the 12th century, Ramon Berenguer III aimed to the south, reclaiming Muslim territories, which were then divided into small reigns (Reinos de Taifas). His son, Ramón Berenguer IV (1131-1162) continued the policy of expansion, conquering Tortosa and Lleida to the Muslims and marrying the King of Aragón's daughter, Peronella. It enabled his heir to detent both titles, a remarkable achievement that would enhance the political expansion of Barcelona as an important part of the confederation. Alfonso I (1162-1196) became, therefore, the first king to unite the throne of Aragón and the countship of Barcelona. The newly formed state-nation evolved towards its territorial climax under Jaume I (1213-1276), who led the conquest of Mallorca, Valencia and Ibiza and Pere III (1276-1285), who sponsored the occupation of Sicily[16]. At the end of the 13th century and during the first part of the 14th, Barcelona played a central role in one of the most important empires of the Mediterranean. The trading opportunities that aroused from this prevailing position had a notable impact in the socioeconomic and physical evolution of the city.

The earliest expression of this period of prosperity was the consolidation of the incipient boroughs outside the walls, which acquired a new dimension to accommodate the new population. Many of them were now referred to as the "new villages" ("Viles Noves"). The road towards France continued to be the most dynamic axis of urban expansion. The channel of the former Roman aqueduct, which carried water from River Besòs, had been restored and it was now an important infrastructure. The Rec Comtal not only supplied water for the people and orchards of Barcelona, but it also provided energy to operate mills. Vila Nova del Mercadal, which was located adjacent to the northeast gate (Portal Major or Main Gate), would soon connect with the emerging villages that agglomerated around churches and junctions on this main road (Sant Cugat, San Pere). Vila nova dels Arcs emerged just off the northwestern gate, Portal del Bisbe, and, finally, the most populous borough was thriving in "vila nova" del Mar, the borough of the seamen. The urban growth to the southwest (vila nova del Pi) was more modest as it was heavily constrained by the presence of marshlands and stagnant waters (Cagallel). The urbanization of this area did not take place until the 14th century. The construction process was based on the sequential occupation of plots along the main roads with detached houses that would gradually transform the roads into urban streets. The prevailing typology was the "artisan's house", two or three-storied buildings with the ground floor dedicated to workshop and the remaining levels to living spaces for the family of the artisan and, potentially, apprentices. The typical house was 4m wide by 10-12 meters deep with a small backyard to grow vegetables for self-consumption[17]. Blacksmiths, stonemasons, builders, weavers, shoemakers or teasers were among the trades that provided the livelihood to these families. The immigration, from rural areas but also from abroad, was constant during the 12th and 13th centuries, fostering a constructive fever that would, one the one hand, weld the boroughs together and, in the other one, enrich landlords who could speculate with land.

Inside walls, social and political evolution was reflected on the fabric. The main transformations were undertaken in institutional buildings. The New Castle (Castell Nou) to the southwest, Regomir's Castle at the seafront and the Palace of the Count at the Main Gate, represented the political power, whereas the church had the Episcopal Palace and the Cathedral on the northeast gate. The civil power was organized in the Consell de Cent (the council of the one hundred), an advisory board that ¡ regulated urban affairs, such as water supply or construction control. It conducted their meetings at the county hall, built in the 14th century. The Jewish district was flourished close to the New Castle (Castell Nou) during almost three centuries. It was detached from the rest of the city, as the Christian church and the other residents did not approve their practices (e.g. usury) and were jealous of their wealth.[18] Although they proved a handy support to provide for the financial needs of the Counts, Jewish were finally expelled, due to popular pressure, by end of the 14th century. Some current streets names give a clue on the location of guilds and specialized crafts (bridle making, paper binding, scrolls, herbs, species, etc...) that remained within the walls, particularly in the northeastern part, close to the market, during a great part of the medieval age.

In the 13th century, the merchants of Barcelona took advantage of the political expansion over the Mediterranean Sea. They established economic delegations in the most important ports. The bourgeoisie had amassed a fortune after investing in real estate during a period of continuous urban growth. The boroughs formed now a continuous fabric, surrounding the old precinct. The new population out of the wall needed a defensive system. The new wall was

16 Sobrequés i Callico, 2008 p. 55

17 Busquets, 2004 p.46

18 Vinyoles, 2006

16th century

Urbanized Area:
112 ha

Population:
35,000

Density:
311 ppha

Fig.9-15 Current characteristic urban form at Raval Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

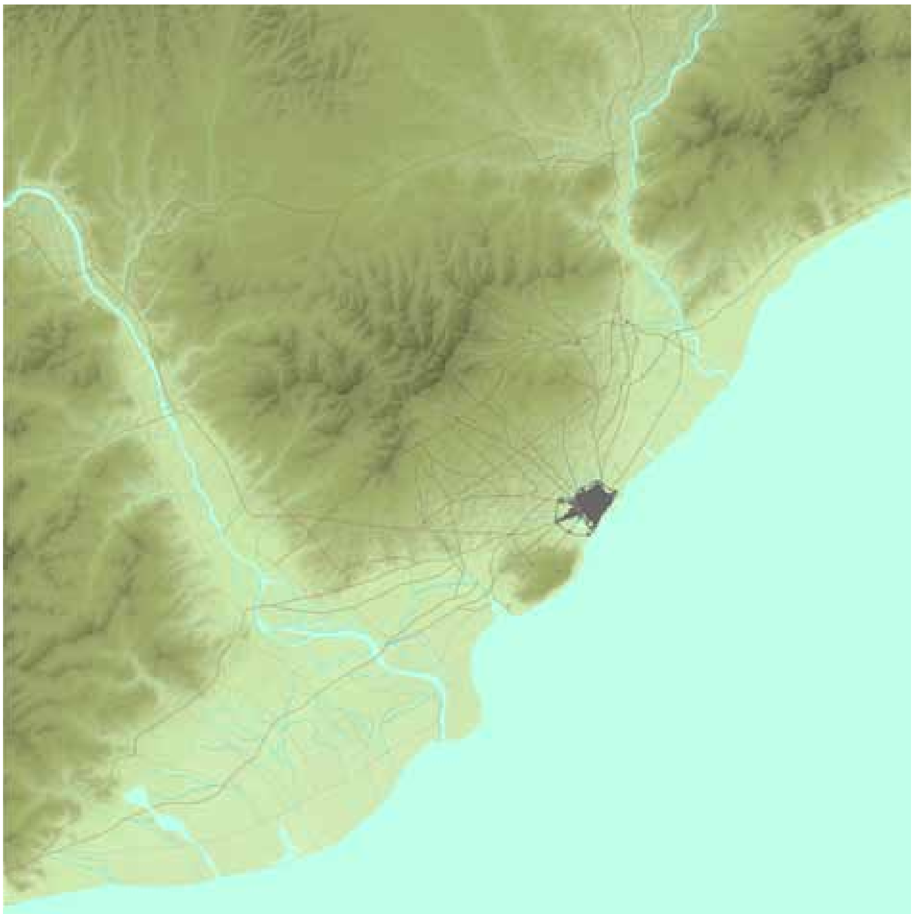


Fig.9-14 Barcelona Metropolitan Area in the 16th century

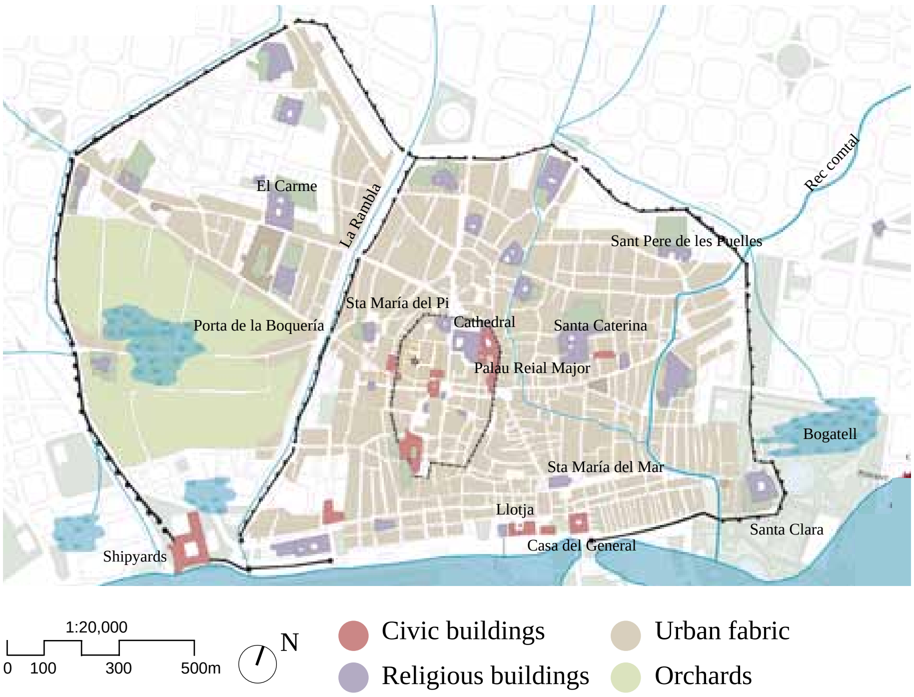


Fig.9-16 Barcelona in the 16th century. The city expands to Raval (source:Vinyoles, 2006)

started in 1260. Eight gates were initially built at the main communication axes. Then, the wall would be gradually erected, to enclose the new agglomeration. The defensive system was supplemented with small defensive forts which were dispersed over the surrounding territory, such as the Castell del Port in Montjuïc or the castles of the plain (Castell del Montcada at Besòs or Castell Vell of Rosanes). The southern boundary of the new wall was initially delimited by the channel of the Riera de St. Miquel, the current Rambla, but the great expectations aroused by relentless prosperity led to a further expansion beyond the Rambla. This area, known as Raval, was dedicated to agriculture and it was scarcely populated, with only few houses and several hospitals. The obstacle of the marshy soil could be now counteracted by rising land prices. Therefore,it was decided that a third wall would protect the Raval as well. The expectations were however not fulfilled as the area remained mostly vacant until several centuries later.

By the end of the 14th century, the only part of the city that was not surrounded by the wall was the seafront. The seafront was dominated by the royal shipyards (Drasanes) in the south and the symbolic profile of Santa María del Mar in the north. Despite the intense maritime trade being sponsored from Barcelona, the city lacked a proper port. Goods were unloaded in the beach by smaller barges, and the only protection of a small promontory, in front of the current Llotja de Mar (fish market). The construction of the port would be undertaken from the 15th century.

9.4. The early modern period

The transition from the medieval to the modern society was the result of a lengthy traumatic period. The prosperity and growth of the High Middle Ages was followed by a deep crisis that reached every aspect of urban life. Cities around Western Europe were shrinking, mostly due to the black plague. Barcelona, as London, was not an exception and the high mortality abated the demographic growth that had characterized the previous era. Further problems were rooted in the inequitable nature of feudalism. The oppressive living conditions of the countryside gave rise to successive peasant revolts that caused thousands of casualties. These were, however, rather common issues in other regions too, but in Barcelona their effect was multiplied by a particular context. The advent of Castilian kings to the Spanish throne (united to the kingdom of Aragón since the Catholic Kings) led Catalonia, in general, and Barcelona in particular, to a marginal position in the national politics. It did not help to reverse the socioeconomic crisis. But in such a large period, there were also some moments for progress and affluence, such as the globalization fostered by the great discoveries. The ups and downs between the centuries 15th to 18th were reflected in Barcelona's urban fabric, rather than on its overall form. The city remained constrained within the wall of the 13th century, because of the demographic crisis first and due to economic reasons later (it could not be afforded). However, new facilities and large scale transformations were critical for the transit of Barcelona towards industrialization.

The urban population had reached its peak in the early 14th century. It has been estimated that Barcelona had, at that time, nearly 50.000 inhabitants[19]. It was among the twenty most populated cities in Western Europe, close to London, Bruges or Toulouse but still far from the big city-states such as Venice, Florence or Genoa. A sequence of negative events induced a long period of demographic stagnation that did not end until the 19th century. The contraction could have been stronger, had constant flow of immigrants not replaced part of the population loss. There were three main causes for this demographic decline, some of them were repeated in successive waves:

Famines derived from the shortage of cereals. Political conflicts and the increase of piracy in the Mediterranean provoked different episodes of food deprivation. They were especially virulent in the 14th century, during the disputes with Genoa. Periods of shortage affected the city regularly until the 18th century, undermining the slow demographic recovery.

The black plague was perhaps the most devastating single cause of urban mortality. It struck Barcelona badly in 1348. Deadly outbursts were dated as late as the 18th century. Unlike famines, pests did not differentiate between classes and a great part of city councilors died victims of the epidemic. As in other parts of Europe, the Jewish community was blamed on bringing the plague, which caused a wave of anti-Semitism and led to their eventual expulsion of the city (not before their district was plundered by angry crowds)

The third main obstacle to demographic growth was the war. During this period, Barcelona was involved in innumerable conflicts. Although the city has rarely been a battlefield itself, the effects of successive wars were considerable, both terms of direct casualties and economic recession. The territorial expansion in the Western Mediterranean and the disputes with the Kingdom of Castile were the main cause of conflict in the 14th and first half of the 15th century. The Civil War in the mid the 15th century had devastating consequences for Barcelona's merchants. They lost their privileged position in maritime trade. During the peasant revolts, known as "remençes"[20], of the 15th century, the rebels took the conflict to the gates of the city. Hostilities were less intense during the 16th century but that was the prelude of a milestone in the history of Catalonia: La Guerra dels Segadors (Reapers' War, 1640) that can be summarized as the Catalonians allying the French band in the Thirty Years War due to general discontent generated by high taxes in a

19 Sánchez Martínez, 1991
20 In English, serfdom

17th century

Urbanized Area:
120ha

Population:
45,000

Density:
373pphа

Fig.9-18 Current urban form at Raval after renewal Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

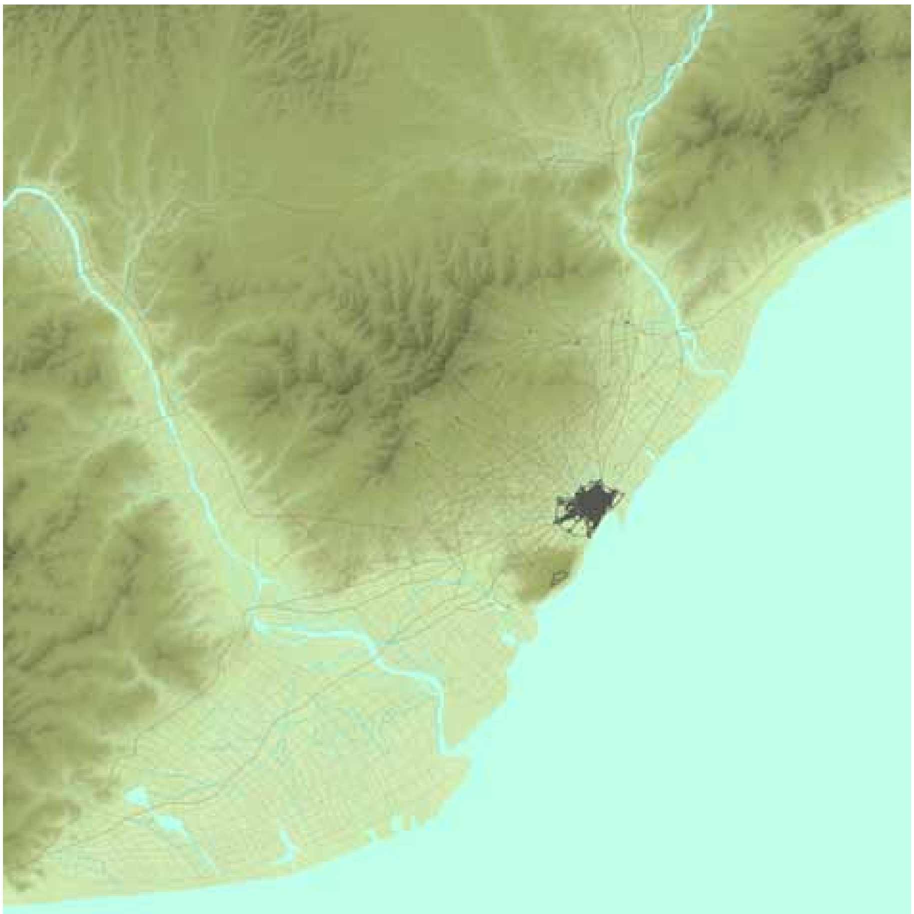


Fig.9-17 Barcelona Metropolitan Area in the 17th century

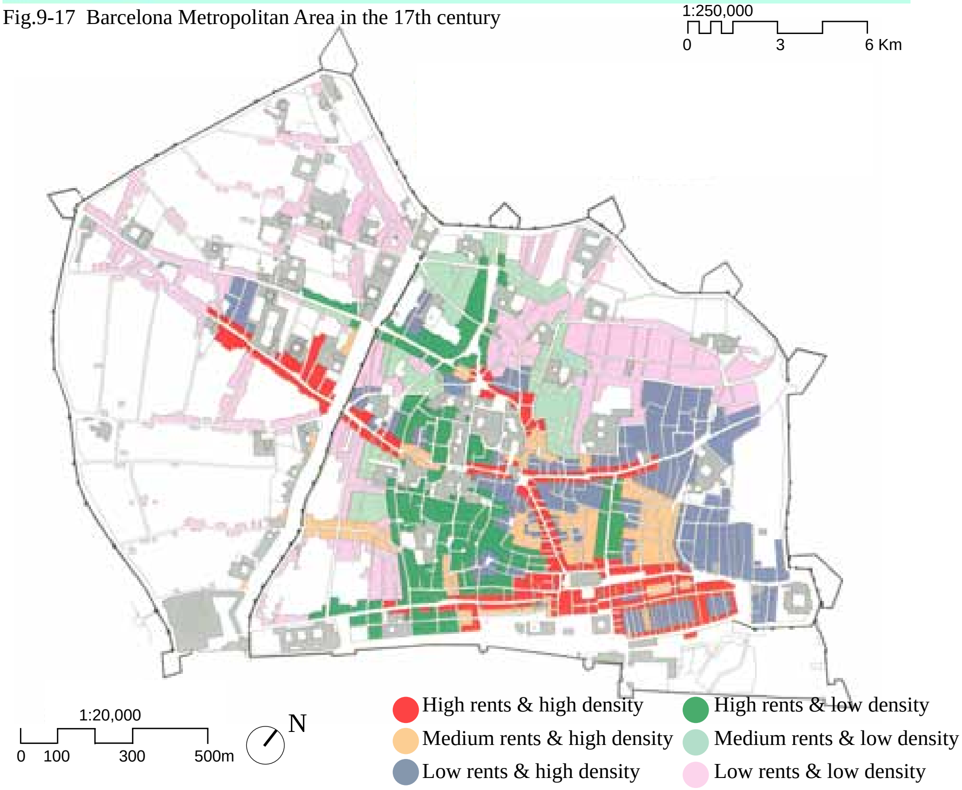


Fig.9-19 Barcelona in the 17th century. The city expands to Raval (source:VVAA, 1994)

recessive economy to finance the military campaigns of the Spanish emperor. This time, Barcelona became a battlefield. First in the battle of Montjuïc (1641) where the Spanish army was defeated by the Catalonian-French alliance and later in a naval attack to the city (1642), which was repelled by the allies. The Spanish troops recovered the control of the city in 1652 after a siege that lasted several months. The Treaty of the Pyrenees (1659) put an end to hostilities and the rebel regions were not severely punished. However, Catalonia had to give up part of its territory (Roselló, Perpignan) to France. Four decades later, Catalonia would ally again with the loser band in the Secession War, the battle to succeed the last Habsburg king, Charles II, who had died without a heir. Phillip V, the first bourbon, imposed absolutism and a heavily centralized government. He suppressed the traditional privileges and the independent institutions of Catalonia (and other seditious territories). A decree of Nueva Planta (New Ground) enforced the abolition of the Consell de Cent and the Generalitat (the regional government of Catalonia) and imposed the military control of the city in 1716.

The society of Barcelona was very polarized. The oligarchy that ruled the city from the Consell de Cent did not necessarily defend the common interest but the interest of wealthy landowners and rich merchants. The artisans and guilds were subdued by the lack of representation in the council. The situation led to the confrontation between two opposing parties: the artisans and small merchants (named "Busca") and the richest families ("Biga"). The formers were concerned with the textile industry whereas the latters' main concern was to keep their privileges and high rents. Native nobles were discontent under the rule of Castilian kings (the lineage was started with the brief reign of Fernando I, from the house of Trastámara, in 1412), who had shown little interest in the problems of the region and exerted a tight control over the nobility. The royal support to the artisans' party and to peasants' claims would elevate the level of opposition of the Catalonian oligarchy and it would trigger the Civil War of the 15th century.

The commerce with species, which had been very lucrative, fell dramatically and the perspectives for the economy were further worsened with the arrival of the Spanish Inquisition to Barcelona. The ruthless practices of this institution scared off many conversed Jewish, who were instrumental to finance commercial ventures. The economy of Barcelona had to wait until the 18th century to experiment a sound recovery. The era of the Spanish Empire did not immediately benefit the exports from Barcelona since neither Carlos V nor Felipe II varied the centralist approach of former Castilian kings. In 1550, the monopoly of the port of Seville expired and some manufactured products could be directly shipped from Barcelona to the West Indies but it won´t be until 1778 when free trade is definitely enforced by Carlos III.

In 1525 the ambassador of Venice, Andrea Navagero, arrived to Barcelona in his way to the Court in Toledo, he stayed in the city for almost two weeks and left a detailed description of his impressions:

"Barcelona is a most beautiful city, and very well located; it has many gardens with myrtle, oranges and lemon trees. The houses are solid and comfortable, made of stone instead of earth, unlike in other places of Catalonia."[21]

His view confirmed a previous account made by the ambassador of Florence, who had visited the city in 1512 and depicted the city as a quiet and comfortable place:

"The city stretches over a plain that follows the sea, and take a suitable location for commerce that, however, does not flourish as much as it did in the past, hence the city is not as rich as in past times and that has been aggravated by the absence of the Court, which is now in Castile. (...) Overall, the city is beautiful and magnificent for its building, for the sea that washes it, right beside the trading market, for its beautiful streets which, although narrow, are clean and well aligned, because it is very populated, because it is rich and, notwithstanding the internal disputes, is extremely quiet. Despite all this, if affect does not shadow my judgment, it is not comparable to Florence, which surpasses it by the luxury of their private and public buildings and poses more beautiful and cleaner streets, although that is a characteristic that Barcelona is proud of."[22]

These descriptions are however general and fail to reflect the contrasts between different parts of the city. According to Segura i Mas[23], the inherited medieval structure, could be divided in three distinguishable areas:

- To the East, the first boroughs were now a densely populated area. Nearly 40% of Barcelona's population was concentrated on that zone, which only represented 14% of the area. Manufacturing, light industries and artisans crowded the streets around Santa María del Mar and the markets of Born and Llotja. The mills along the Rec Comtal provided energy and water for textile industries
- The former Roman enclosure was now an institutional and excusive residential zone. Nobles, big merchants and clergymen had their residences around the Cathedral, the Generalitat and the City Hall.
- The poorer houses were at Raval, still a low density area with orchards and open fields.

21 Quotation translated from Sobrequés i Callico, 2008 p. 122
22 Ibid, p.95
23 Segura i Mas, 1991

c.1717

Urbanized Area:
134ha

Population:
34,000

Density:
253pphа

Fig.9-21 Current characteristic urban form at Riera Alta. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

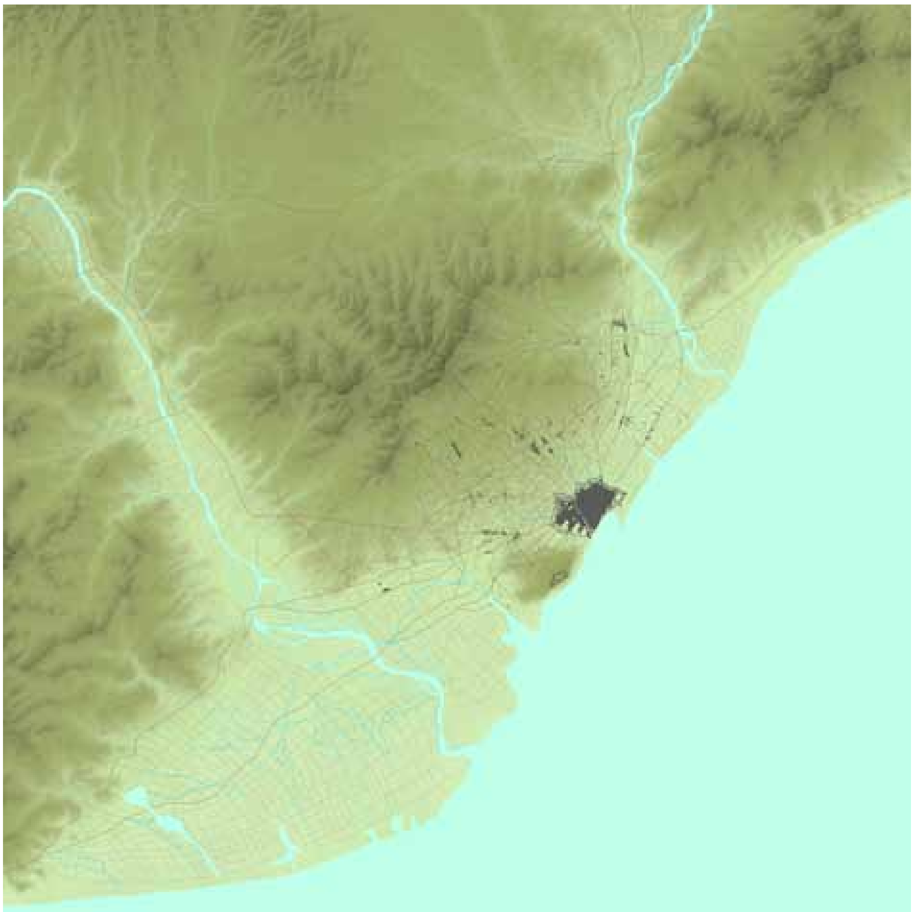


Fig.9-20 Barcelona Metropolitan Area in the 18th century

1:250,000
0 3 6 Km

Fig.9-22 Barcelona in the 18th century. (map by Paul Rapin de Thoyras,c.1740)

1:30,000
0 100 500 1000m
N

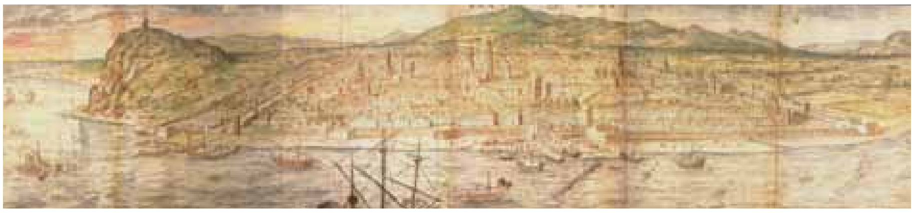


Fig.9-23 Barcelona in 1563 by van den Wyngaerde

The many shades and few lights of this period made difficult any prospect for urban expansion. The continuous state of war and the demographic fluctuations prevented any adventure beyond the protection of the wall. However, as any other historical time, the preindustrial society also left its mark on the internal structure of the city. The different forms of habitation weaved the medieval streets but the construction pace was very slow due to the economic and social crisis. The volume of the built fabric remained modest until the 18th century, when the demographic explosion (over 100,000 inhabitants by the end of the century) caused a dramatic increase in building density, mainly absorbed in the addition of further dwellings on top of existing structures. The polarization of the urban society was reflected in the different types of accommodation. The poorer families lived in tiny flats, barely lit by a small window that opened to a narrow street. In the Ribera neighborhood, the district of the seamen, it was common that the whole dwelling was developed in a single space. Sobrequés i Callico states that these humble construction are, indeed, the predecessor of the barraks, self-built constructions that derived in the shanty-towns of the industrial era[24].

The demographic explosion of the late 18th century led to a densification of the city, increasing the height of buildings and provoking a change of typology towards collective housing. In contrast, the wealthy families enjoyed much larger houses, with up to fourteen rooms, two stories, basement and an orchard. Institutional buildings protruded among the residential tissues. This was not a particularly active period in terms of new facilities, except for churches and monasteries, which were numerous. Most of the construction activity focused of retrofitting and the addition of new elements to old buildings, using new architectural languages or adapting then to new demands (Shipyards, Montjuïc fortress). The most emblematic civic buildings from these period were the Hospital of Sta Creu, the City Hall, the House of the General and the enlargement of the Shipyards in the 15th century. The Palace of the Deputy (Palacio de la Lugartenencia, current Archive of the Kingdom of Aragón)and the convents of the Jesuits were built in the 16th century. The convents of Sta. Mónica, Belén and Montesión were completed in the 17th century. In the 18th century there was an economic recovery, which was reflected in the palaces that the Catalonian oligarchy made construct around the two noblest streets of the city: the Rambla and Montcada Street. Other urban projects were the construction of the last section of the wall, the citadel, the port and the project of Barceloneta.

The waterfront was totally transformed. In 1439, Alfonso V granted the council with the power to build the much needed port. Works did not start until 1477 and the construction of the wharfs spanned over three centuries, in several successive stages. Under Carlos V's reign, the last section of the wall, at the city's waterfront, was erected. An empty strip was left between the wall and the city, which would enable its future use as a representative space when, in the 18th century, the Pla de Palau was urbanized. This plan included the construction of important institutional buildings, transforming the area in a new centrality. The Palace of the General Captain symbolized the military and political power, the new "Llotja", which became the place for economic transactions,[25] and new teaching institutions were located there, together with the Customs House.

The militarization of the city, after the Decree of New Ground of 1716, had a major consequence in the urban fabric: the Citadel. The aim was to discourage any potential insurgence by the threatening presence of the military complex at the heart of the city. In the event of rebellion, it would allow the rapid deployment of armed troops. The construction of the fort implied the demolition of hundreds of houses in one of the densest part of the city, the Ribera and Sant Pere districts. Residents were not given any compensation. They would be rehoused at Barceloneta more than thirty years later. The project of Barceloneta was the first significant expansion of the city since the consolidation of the medieval perimeter in the 13th century. Based on a project of the engineer Martín Cermeño[26], the district was a prime example of neoclassic urban design. The project was based on a functional grid and the modular repetition of the building unit. The streets were arranged to enable visual control from the citadel and Montjuïc fortifications. The initial housing type was a detached dwelling of 8.4 by 8.4 meters, with two floors and double façade that allowed cross ventilation. Later intensification of the neighborhood led to a profound transformation and a substantial increase in density. Currenlty, the 24 hectares of Barceloneta are occupied by nearly 25,000 inhabitants in about 6,000 dwellings, which gives an average over 1,000 people per hectare and 250 dwellings per hectare[27].

24 Sobrequés i Callico, 2008 p. 87

25 Busquets, 2004 p.89
26 Sobrequés, 2013
27 Busquets, 2004 p.95

c.1850

Urbanized Area:
144ha

Population:
121,815

Density:
845pphа

Fig.9-25 Current characteristic urban form at Vila de Gracia. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

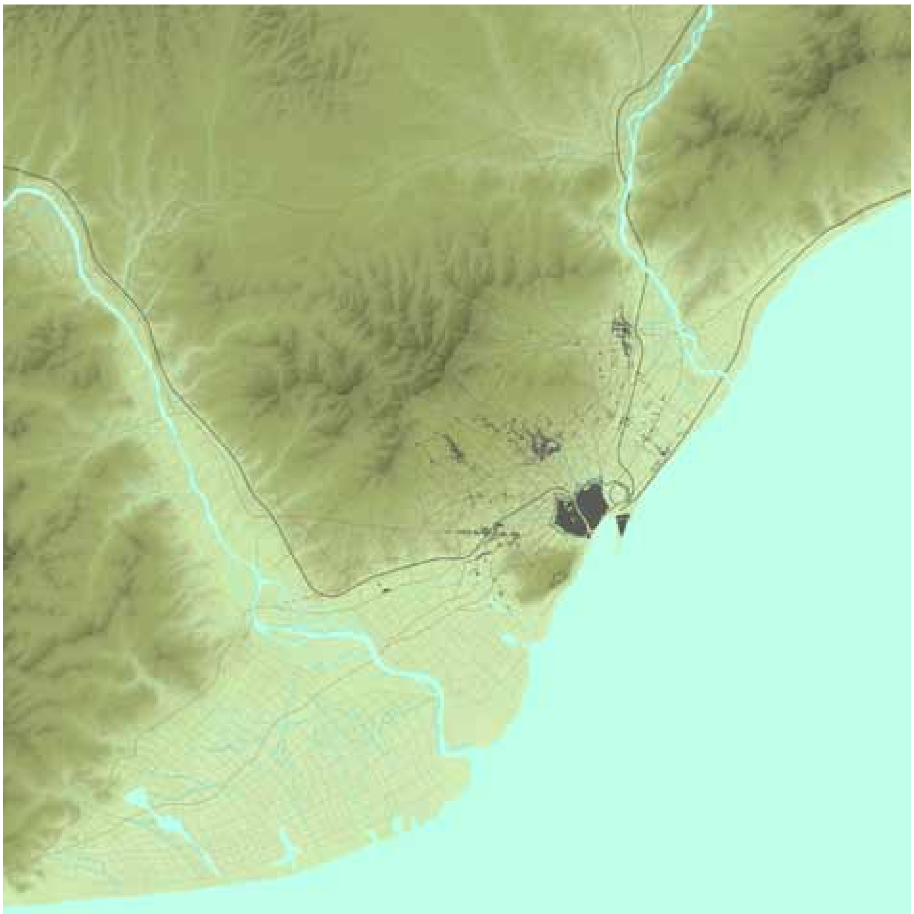


Fig.9-24 Barcelona Metropolitan Area in the 19th century, with the railway lines

1:250,000
0 3 6 Km

Fig.9-26 Topographic map of Barcelona 1855. The new suburbs, Gracia,Hosta,San Andrés de Palomar..., have emerged (Cerdà, 1855c)

1:70,000
0 1000 2000m
N

Fig.9-27 Housing typologies. During the first half of the 19th centuty, the prevailing housing typology evolved from the artisan’s house (left) to collective housing, in order to absorb the high densification within the walls (VVAA, 1994)

9.5. Industrialization

By the end of the 18th century, much of the former agricultural fields at Raval were being occupied by emerging industries. The textile manufacturing sector was particularly active, waving and calico factories quickly adopted modern machinery to improve their competitiveness. The medieval system of guilds, workshops and apprenticeship was being replaced by entrepreneurship, smoky chimneys and mass workers. It was the prelude of the Industrial Revolution.

As in other industrial capitals, waves of immigrants were attracted by the new jobs. In the initial years they mainly came from the rural periphery but by the end of the 19th century and, especially, during the 20th century, they also came from other parts of Spain. In less than two centuries, Barcelona’s urban population grew from 34,000 (1717) to over 500,000(1897) inhabitants. It would continue to grow until the 1970s. Industrialization, the new demographic scenario and the introduction of new technologies in transport and urban services were critical elements in the configuration of the modern city.

The industrialization of Barcelona had, however, its own peculiarities that made it different to British pioneering cities. There were important limitations that could have prevented the success of an industrial economy. Barcelona could not rely on its own resources as they were either insufficient or of low quality. The coal to run the factories was mainly imported from England and raw materials (mainly wool) for the textile companies was also imported from abroad (e.g. United States). The Catalonian industries had to provide an added value in order to be competitive against other production centers. They based their advantage on their tradition in manufacturing textiles and the constant search for new markets and commercial opportunities. However, sometimes this was not enough and protective tariffs were frequently requested to the central government in order to secure the preference of Catalonian products over foreign firms in the national market. Barcelona had no rival in Spain[28] as only the Basque Country developed a modern industry (metallurgy), and could hence benefit from the internal demand and commerce with the former colonies.

There were two zones where new factories clustered. The plain could not be occupied for it was banned by military laws. Consequently, the new premises had to be accommodated within the walls. The first zone was the aforementioned area of Raval, between the second and third wall to the southwest of the city, at the bottom of Montjuïc. The last vacant plots within the walls favored the construction of industrial facilities in that part. Some factories were built on former convents and monasteries that had been vacated after the general confiscation of monastic properties enforced by Isabel II’s minister Mendizabal[29] in 1837. The other zone was the former borough of Sant Pere, where Rec Comtal was used to generate hydraulic energy for a long established textile industry. The workshop and artisan typologies still prevailed in this borough, with much smaller factories than those at Raval.

Steam was used for the first time in Spain at Bonaplata factory, at Raval, in 1833. The factory was burned down only two years later as new technologies were demonized by workers who saw them as a replacement of manpower. However, a new factory (El Fénix) was built over its ashes and steam powered industries multiplied. In 1947 the harmful environmental consequences of the proliferation of factories in the old city were evident and the Council banned the construction of new ones within the walled precinct. The old towns of the plain such as Sants, Gràcia, Les Corts, Sant Andreu and especially Sant Martí de Provençals (current Poblenou) started to accommodate large industrial complexes. At that time, the removal of the wall and the expansion of the city was one of the main concerns of the Council. When they finally succeeded in their request, the

28Engels defined Barcelona as the greatest industrial enclave of Spain (Segura i Mas 1991.). Other authors refer to Barcelona as the Manchester of Spain (Sobrequés i Callico, Busquets)

29 The Church allegedly supported the rival of Isabel II during the Succession War

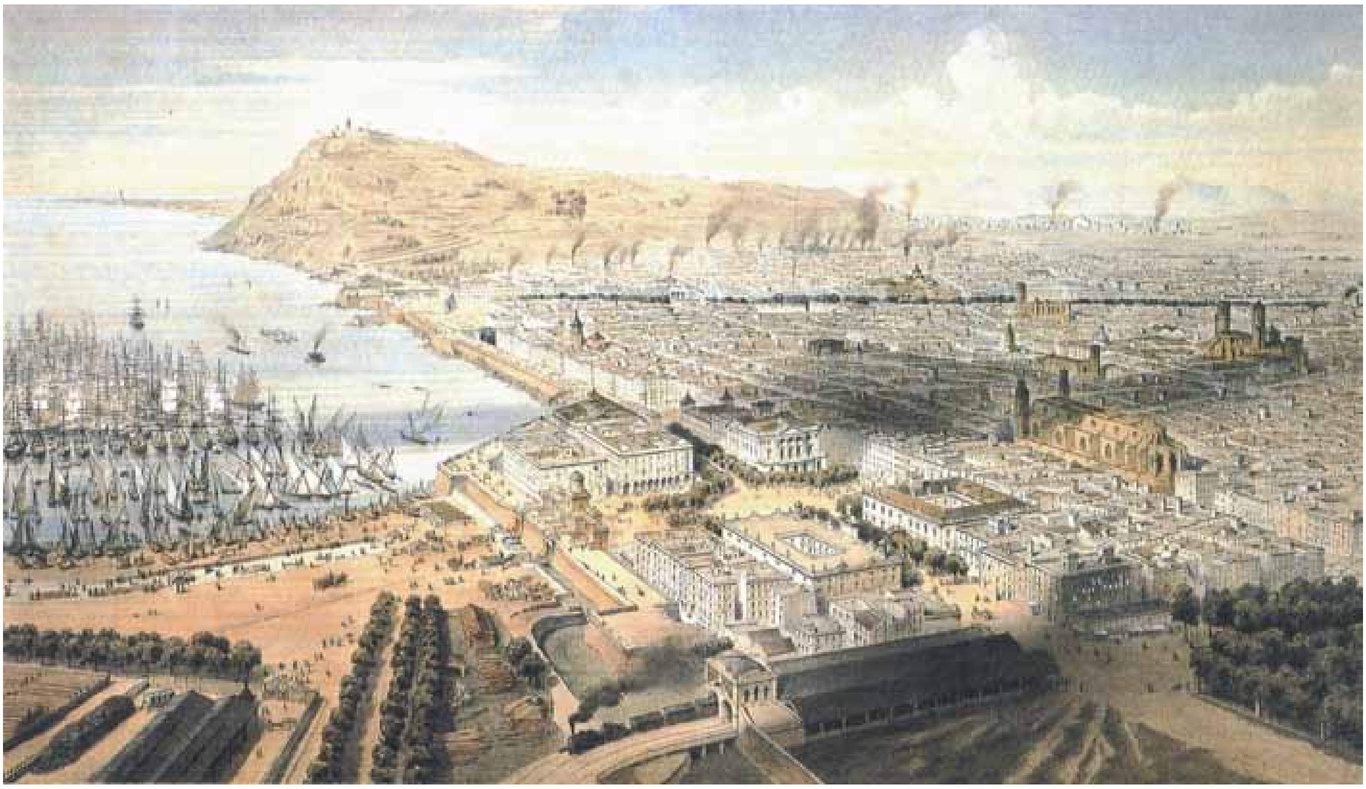


Fig.9-28 Barcelona in 1853. The smoky chimneys have populated the city, especially beyond the Rambla, at Raval. Engraving by Alfred Guesdon

gradual colonization of the plain was accompanied by the construction of new industrial facilities in the emerging metropolitan area. The construction of the first railway lines fostered the active development of industrial activities in other Catalonian towns. The very first rail itinerary of Spain connected Barcelona and Mataró in 1848, where thirty five cotton-mills and thirty four knitting factories depended on the raw material supply that arrived from the port of Barcelona[30].

According to Busquets[31], the modern Catalonian industries were built in two different models, strongly determined by their primary energy source: the "vapor" (steam) model, powered by coal and the "colonia" (colony) model, powered by hydraulic power. The two systems originated two urban scenarios. Coal powered facilities were more compact and they were typically inserted into the urban fabric whereas the colonies were self-sufficient urban enclaves, with their own services (church, school, stores...) and, sometimes, even the workers' residence were part of the complex. Examples of the former have remained and they are now an important Industrial Heritage (e.g. Can Ricart, Casaramona or Can Batlllò).

The demolition of the city walls was the most decisive event in this period and, perhaps, in the history of the city. The issue was not a simple one as the socio-political scenario in 19th century Spain was highly unstable. The century had started with the Spanish Independence War against France, followed by the absolutist regime of Fernando VII and a Succession War after his death. The reign of Isabel II, who prevailed in the succession dispute, was also convulse and finished with her exile after the Revolution of 1868 succeeded. A six-year democratic term, two brief republics and two monarchies, including a period of military dictatorship, alternated in power for half a century, until such instability paved the way for the uprising of a so called National Movement, detonating the Spanish Civil War of 1936. In this context, it can be inferred that the removal of the wall was not strictly justified by its obsolescence. If fact, Barcelona had been bombarded by the Spanish Regent, General Espartero, only seven months before the demolition of the wall was requested by the city. The main reason was the unbearable living conditions of the population that crammed inside the medieval precinct, with a density around 850ppha[32], probably among the highest ones in Europe. On the other hand, the wall was also a symbol of the repression that the city had suffered since the defeat of 1714 and the subsequent decree of New Ground. The request was finally accepted in 1854, the liberation from the "stoned straitjacket" enabled a first urban explosion. The colonization of the plain (Eixample) was designed by the engineer Ildefons Cerdà.

30 Sobrequés i Callico, 2008 p. 202
31 Busquets,2004 p.107
32 Ibid, p.122

Fig.9-29 Plan for Reform and Urban Extension for Barcelona by Ildefons Cerdà (Cerda,1859c)

0 1000 2000m N

9.6 The Eixample

Cerdà's Plan has been widely studied and published[33] and it is not the aim of this research to discuss the project in all its angles. The scope of the analysis is to understand the evolution of Barcelona's urban form to its present shape and the Eixample's formation is a landmark in this process. Although the city devised by Cerdà is today celebrated as a pioneering example of town planning and urban science, it was not all welcomed by the local authorities at the time. The Plan was sponsored by the Department of Environment of Spain but not by Barcelona Council, which had launched a parallel competition to choose an alternative project, awarded to the architect Antoni Rovira y Trias. The project by Cerdà prevailed, but the confrontation with the council forced a long period of negotiation to adapt his initial proposals. For instance, his model of ordinance, which established a limitation on ground floor coverage so as to reserve green areas in the courtyard of each block, was discarded and the generic municipal by-law was used until 1891[34]. A common interpretation of Cerdà's documents argued that buildings were to occupy only two fronts of the block whereas the other fronts should remain open. That would be, according to this theory, an absolute condition for Cerdà and it was accepted as mainstream position to illustrate the distortion between the built Eixample and the original concepts. However, a recent research has demonstrated that Cerdà may have been much more accommodating about filling the block's perimeter[35]. Indeed, the final framework was gradually developed over a period of twenty years where the engineer played a prominent role.

Leaving aside the planning procedure, the Eixample has transcended because it organized Barcelona's transformation from a medieval city to a modern metropolis, in a process that spanned for over a century. One of the main strengths of the project, and the reason why it endured throughout different regimes and conflicting interests, was its great flexibility. The robustness of the urban concept allowed a myriad of solutions to take place in the Eixample's fabric without affecting the global coherence. Cerdà's thorough work was not an ad-hoc solution for a particular city, but part of a wider theory. He elaborated a general methodology, pioneering modern Town Planning and urban science, in which he combined fieldwork surveys (he ordered a high resolution topographic map, 1/1250 of the plain before undertaking the project), statistic analysis, study of precedents and a preliminary theoretical statement to explain the basic elements of the plan. The preparatory documents, some of which were discovered in the 1980s, are an invaluable source of information to portray 19th century Barcelona[36] and a proof of the comprehensiveness of Cerdà's approach.

33 See for instance:

AA.VV. 2009a, AA.VV. 2009b, Tarragó, 1994 , Sabaté, 1999

34 Busquets, 2007

35 Sabaté, 2007

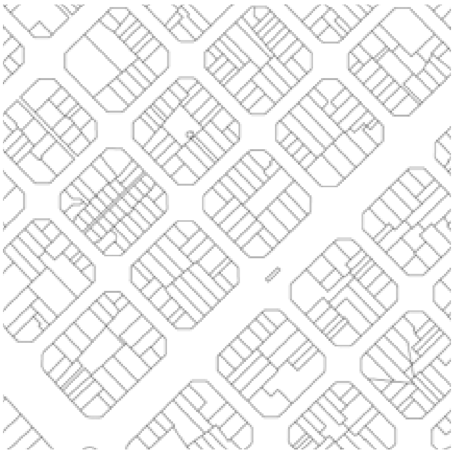
36 See for example Cabré & Muñoz, 1994 Soria y Puig, 1996

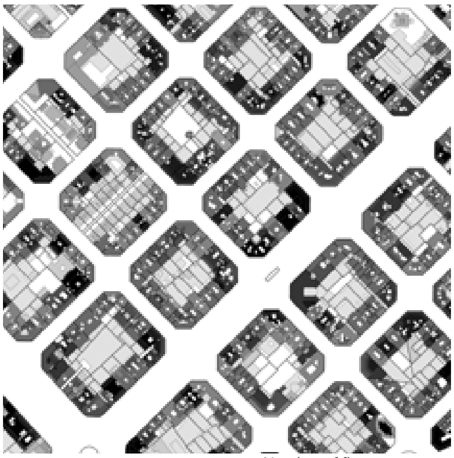
c.1900

Urbanized Area:
828ha

Population:
533,000

Density:
643ppha





1:10,000
0 50 100 200m

Number of floors
1 2 3 4 5 6 7 8 9 ≥10

Fig.9-31 Current characteristic urban form at Eixample Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

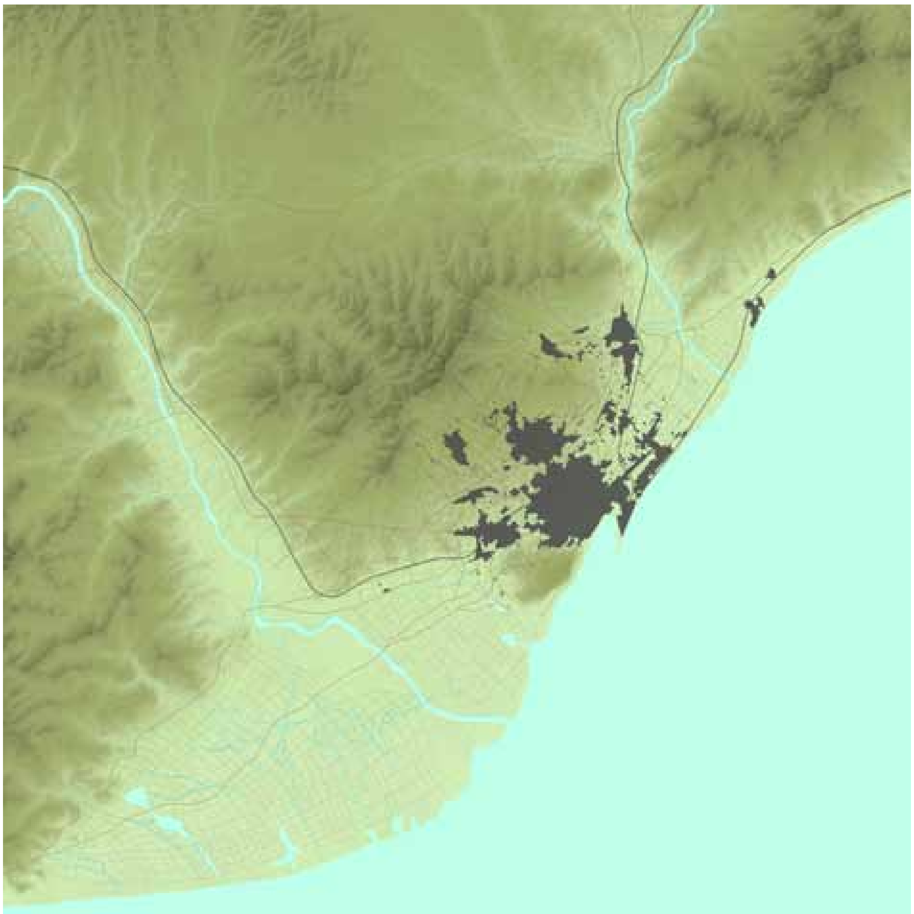


Fig.9-30 Barcelona Metropolitan Area c.1900

1:250,000
0 3 6 Km

Fig.9-32 Barcelona city in 1900 (map by Wagner & Debes, 1901)

1:60,000
0 1000 2000m
N

The most distinctive spatial feature of the Eixample is, without a doubt, the characteristic grid, composed of squared blocks with chamfered corners. However, the critical review of the plan has highlighted some other aspects:

- **The metropolitan character of the plan**. The extension had to be limitless in order to avoid the imbalances of the past. Setting boundaries to urban expansion would lead to the repetition of problems such as congestion, speculation and housing shortage[37]. On the other hand, Cerdà was well aware of the potential of the railway and the change of scale that its general implementation would induce. He had designed the railway project from Granollers and Abadeses so that he had a firsthand experience about the prospects of the new mobility[38]. The plan included not only Barcelona, but also the municipalities that surrounded it. In that way, it anticipated the formation of a metropolitan area, then confirmed by the incorporation of Les Corts, Gràcia, Sant Andreu de Palomar, Sant Gervasi de Cassoles, Sant Martí de Provençals and Sants in 1897 and exceeded by the further addition of Sarrià, Sant Adrià and L'Hospitalet in the first third of the 20th century. The main avenues conceived by the plan, those which broke the homogeneity of the grid, emphasized the connectivity between the old peripheral towns with the centre and the port. The transition between the territorial to the local scale was solved by the hierarchy of the network. Apart from the metropolitan axes, there were thoroughfares of a second order, and local streets of a more private character called "intervías" (intra-ways).

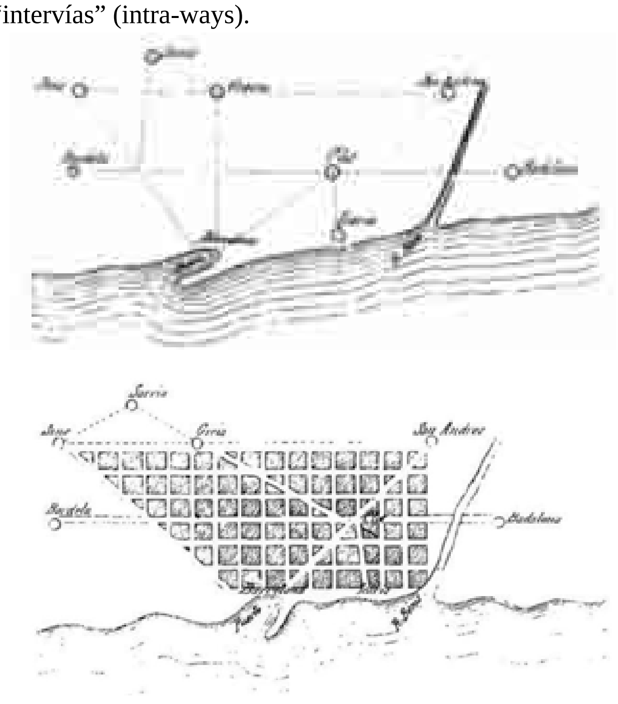


Fig.9-33 Draft schemes by Cerdà (Cerdà,1859a) showing the structure (top) of nodes and arteries and its combination with the grid (bottom)

37 Cerdà, 1859a

38 Magrinyà Torner, 1999 pp.95-117

- **The hygienist component of the new city.** The Eixample was conceived as a new city, juxtaposed to the old one, which, in the initial concept, should be subject of a profound internal reform (that part of the project was never implemented). The high density of the walled enclosure multiplied the harmful effects of the industrial emissions. The mortality rate was dramatic, especially among the poorer classes (living expectancy of 19.7 years in 1837-47[39]). One of Cerdà's preparatory documents dealt specifically with the living conditions of the working class. It has been postulated that he was also aware and receptive to Henri de Saint-Simon's utopian philosophy[40], from where he could have absorbed some of the ideas for a healthier and fairer society. Numerous hygienist principles can be indentified across the plan. Wide streets, a generous proportion of gardens to blocks and a climate and solar analysis performed as part of the project statement are some examples. The plan also addressed the reform of the old. It proposed the demolition of some existing blocks to increase the permeability of the fabric. This part of the document was not approved and the regeneration of the historic city would not be undertaken until the last quarter of the 20th century.

- **The feasibility plan and urban management.** One of the main innovative aspects of the plan was its economic strategy and the methods to fund the urbanization process. Landowners and real estate companies were required to give up the land for roads and to assume the ordinary urbanization costs. In fact, he put into law something that, according to his own accounts[41], was common practice in informal settlements around the city. The main beneficiaries of the surplus generated by the transformation of rural parcels into regular urban plots should afford the economic cost of the process.

- **The physical expression** of Cerdà's Eixample can be identified in the present city by the presence of the regular grid. The urban form is shaped by the repetition of a model, whose aggregation extends like a carpet over the plain of Barcelona, in a similar way as the Roman rural grid did seventeen centuries ago. A possible slogan for the design of the grid could be the "ruralization of the city and the urbanization of the countryside"[42]. In effect, the engineer wanted to ensure sunlight and proper ventilation in all new dwellings. This could be achieved with low density, as in rural environments, but the economic feasibility would be then compromised. He saw a better solution in collective housing, with strict ordinances to limit the depth of blocks and the width of streets. In his preliminary studies, Cerdà had made a typological study of different cities, such as New York,

39 Busquets, 2004 p.130

40 Grau, 2007

41 Cerdà, 1859b

42 Magrinyà Torner, 2009

London or Edinburgh [43](fig. 9-34), to analyze their blocks. On the other hand, he had measured the overcrowding in the old city. He compared it against other capitals and found that Barcelona had the poorest conditions, with barely 13.5m² per person, far behind London (109), Madrid (23), Paris (32), Philadelphia (31), or La Habana (28)[44].

With these parameters, he established a target of 40m² of space per person (equivalent to 250ppha) and designed an urban context that would ensure good living conditions within an economically feasible density. The base of the urbanization was the dwelling unit, not in isolation but as a collective entity:

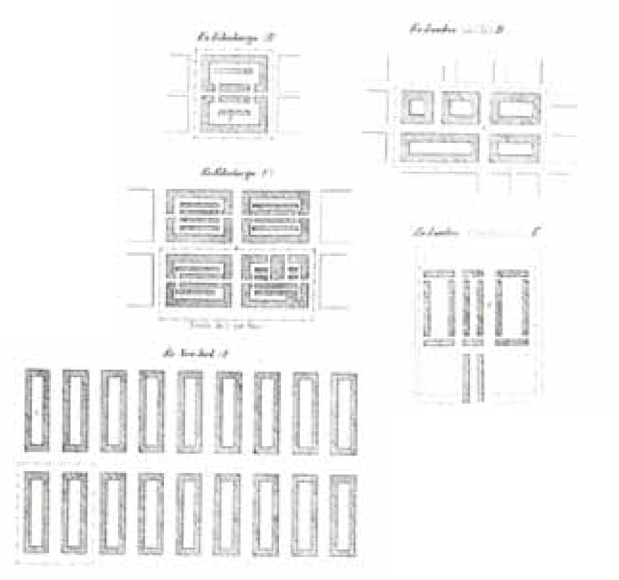


Fig.9-34 Typological studies by Cerdà (Cerdà, 1855)

"The need for shelter that men have and that can be found in all situations and circumstances is the origin of urbanization; and consequently, dwellings are the first constitutive element of it.

(...)Urbanization is much more than one dwelling, and yet more than many dwellings, independently considered. Urbanization, in order to become so, requires the arrangement, more or less organized, of dwellings in such a way that their residents can communicate among them and provide reciprocal services" (Cerdà, 1867)

Cerdà proposed specific housing typologies for different family configurations and detailed studies about dimensions, construction costs, and the rents they would produce[45]. He determined then the land area that should be designated as gardens for the common use of the residents of the block. That would facilitate healthy exercise for children under visual supervision from the house and a safe place for elders to stroll. Once the space occupied by the garden and the house was known he studied the best possible layouts. The most desirable combination was the stand-alone building where no internal shafts were required for ventilation and daylight. However, given the spatial expenditure of that typology he advocated for terraced houses that were illustrated in several schemes (fig. 9-35)

The design of the block was determined by three main aspects:

- First, how the shape affected the hygienic conditions of both internal and external spaces
- Secondly, the proportion between width and depth, which also influenced mobility and value
- Finally, the total perimeter that had to be considered with economy and management on mind

The shape of the block proposed by Cerdà had all the elevations facing streets, which were orientated to the prevailing winds. He justified the squared proportion (equal length on both axis of the block) as a more equalitarian arrangement, as otherwise the mobility in the direction with more junctions (shorter blocks) would be more problematic and therefore it could affect property values on the buildings on that elevation. To obtain the length of the block he elaborated four algorithms, in which the main quantifiable elements were included, depending on whether it was a closed or open block, with or without chamfered corners[46].

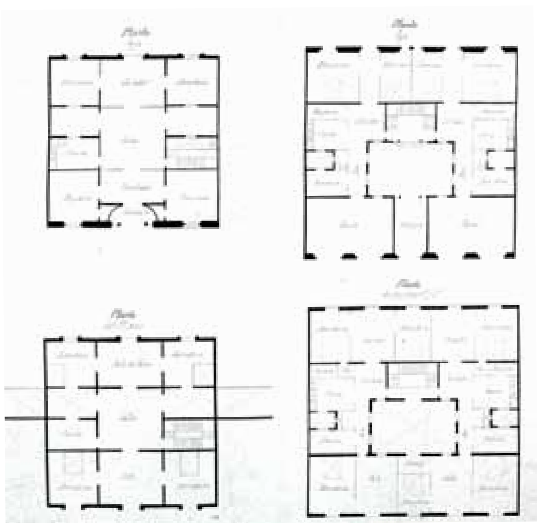


Fig.9-35 Housing typologies proposed by Cerdà (Cerdà, 1855)

The rational abstraction of the grid had been adapted to the logic of geography and the inertia of traditional flows of goods and persons. The port and the various settlements at the outskirts of the military zone[47] were the nodes to be

43 Cerdà, 1855a
44 Ibid
45 Cerdà, 1855b

46 See Magrinyà, 2009 for a detailed graphic explanation
47 Land around the city of Barcelona where construction was restricted due to military reasons since the Decree of New Ground

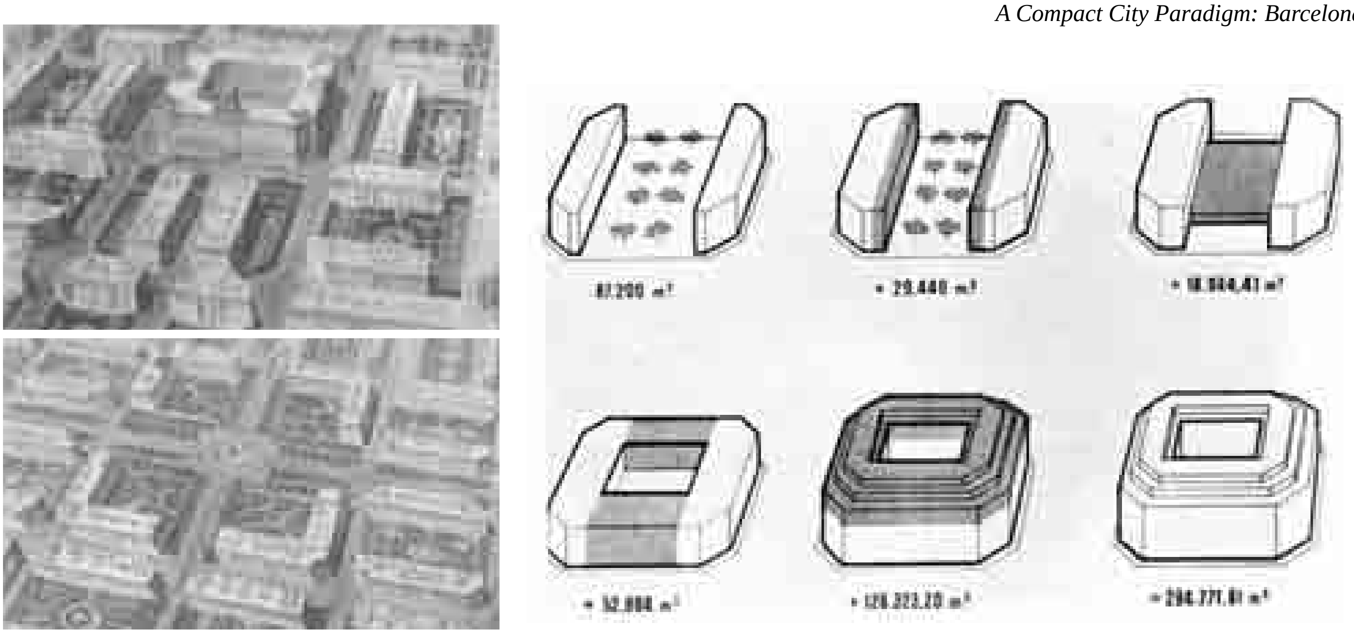


Fig.9-36 Eixample: ideal and evolution. Top left: urban design around public buildings. Bottom left: junction between two main roads (drawings by Francisco Vall, reproduced from Martorell et al, 1970). Right: the gradual densification of the blocks (drawings by Emili Bordoi, reproduced from Galera et al, 1982)

connected by straight roads, thus creating the basic structure of the new city. The topography and drainage were considered in the extension of the grid over the plain. The initial schemes proposed by Cerdà are illustrated in fig.9-33

In summary, the Eixample was ultimately composed by the grid of squared blocks with dimensions 113 by 113 meters, with chamfered corners and separated by 20 meters-wide streets. The chamfers created generous junctions that were, indeed, larger than many squares of surrounding towns. A second structural order was formed by wider streets of metropolitan character, which connected the main suburban settlements with the port and the old city (fig. 9-33)

The actual construction of the Eixample started in 1860 with the survey works and the layout of the first junction (Gran Vía and Via Laietana)[48]. The creation of real estate corporations was fundamental to boost the early development wave. They were formed by many small investors and shareholders from the city that gathered important sums of capital[49]. However, a crisis in 1866 slowed the construction pace down and led some of these societies to bankruptcy. The way out to recession was found, as would become a sort of tradition in Barcelona, by the organization of a worldwide event: the Universal Exhibition of 1888.

Although the Eixample's grid proposed a universal solution for all the vacant space on the plain, there were pre-existent suburban settlements, where the rigid geometry could not fit the existing spatial logic. They had acquired a certain demographic and industrial importance before the plan and, according to Solá Morales, they also conditioned the future growth by generating expectations of profits from the development of intermediate rings.[50] The construction of Cerdà's grid took the medieval city as gravity centre and it expanded outwards. However, at the same time, those suburban settlements were growing into industrial hubs (Sant Martí, Sants, Les Corts, Barceloneta or Gràcia) and working class accommodation areas. The population of the outer ring increased between 1857 and 1900[51] by a factor of four. Both urban models would eventually collide as Cerdà had not foreseen any type of transition between the grid and the different suburban models. Busquets and Parcerisa categorized these models according to their formation processes. They described six main types that operated during the 19th century and other four models that developed during the 20th century. The combination of these ten suburban models and the inner grid can be use to undestand the transformation of Barcelona's urban form during the last two centuries[52]

9.7 The connection with the hinterland. Plan Jaussely

Given the lack of provisions regarding the connection with the suburban villages in Cerdà's documents, the council decided to launch a competition to address this issue in 1897. Right after the administrative boundaries of Barcelona had been reshuffled, integrating most of its surrounding councils (Les Corts, Gràcia, Sant Andreu de Palomar, Sant Gervasi de Cassoles, Sant Martí de Provençals and Sants). The study area for the competition included the new administrative extension and also Sarriá and Horta, which would be annexed

48 Busquets, 2004 p.140
49 Ibid,
50 Solá Morales, et al, 1974
51 Busquets, 2004 p.145
52 Busquets & Parcerisa, 1983

c.1930

Urbanized Area:
2,943ha

Population:
1,400,000

Density:
475pphа

Fig.9-38 1970s blocks. Urban form at Besòs i Maresme. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

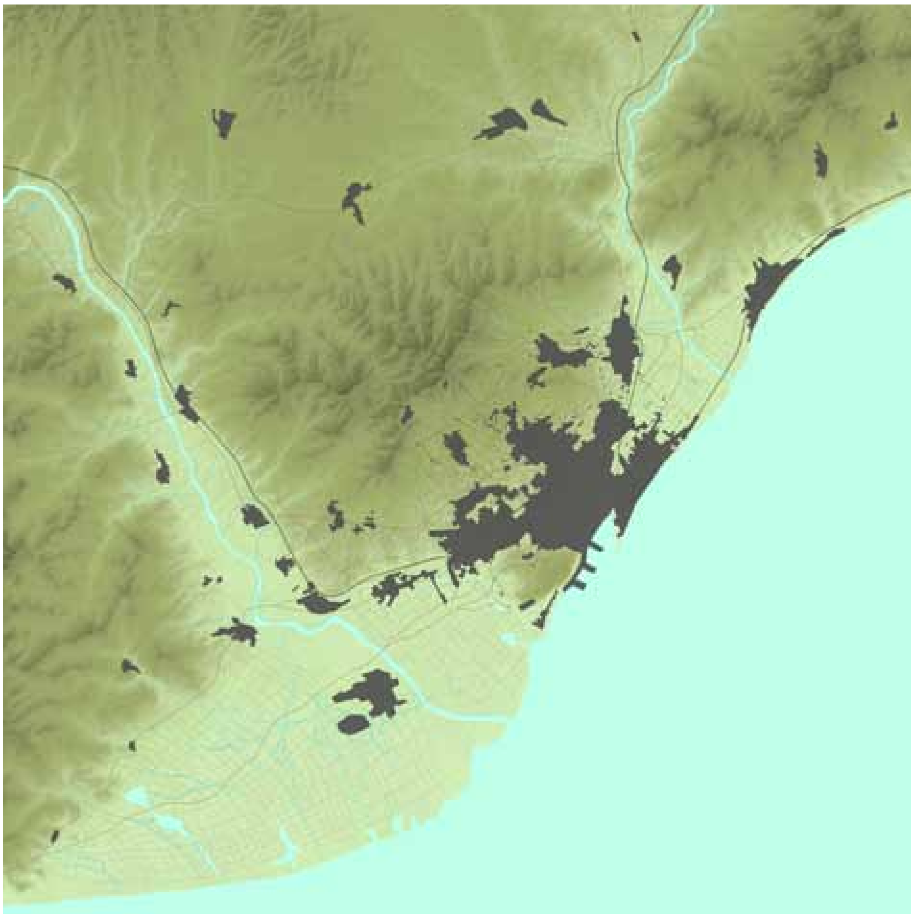


Fig.9-37 Barcelona Metropolitan Area c.1930

Fig.9-39 Barcelona city in 1930 (map by Vicenç Martorell, 1931, Archivo Histórico de la Ciudad de Barcelona)

Fig.9-40 Plan Jaussely, general scheme showing different construction zones and the proposed connections (reproduced from Martorell et al, 1970) N

in the following decades. The brief stated that the target was to "study and shape a preliminary plan to connect the old urban precinct of Barcelona with the recently annexed towns, to connect these among them, and to connect these with the current urban fringe and with the towns of Sarriá and Horta, not yet merged. The projects may propose the extensions, variants, new boundary zones, promenades, ring roads and whatever the rational and logic connection of the different urban or suitable for urbanization areas required"[53] The entry presented by a team led by the French urbanist Leon Jaussely won the contest. The jury praised the graphic quality of the proposal and stated that if the plan was implemented "*Barcelona would become the most beautiful city of the Mediterranean*"[54] The plan Jaussely can be defined by main three lines of action:

- It posed a critical perception on Cerdà's Eixample. Although Jaussely admitted that the wide avenues and green courtyards had greatly contributed to the improvement of the hygienic conditions of the city, the monotony of the grid was unacceptable for current urban standards. He aimed to enrich the Eixample with new diagonal and radial streets that would break up the homogeneous grid.
- The plan also proposed new centralities in the new metropolitan area to offset the excessive accumulation of public facilities in the inner ring. Some of these centralities, such as Les Glories Square, were suggested by Cerdà. Jaussely reinforced their presence and added further urban centers and sub-centers.
- The main target of the contest was to improve the connectivity among urbanized territories. The project proposed radial roads from the main new centralities to the suburban settlements, weaving the Eixample and the first periphery. To connect the suburbs, three ring roads would be laid: the inner Industry Ring Road, the intermediate Ring Road Promenade (Paseo de Ronda) and the outer Rural Ring Road. A complete restructuration of the railway system would complete the mobility plan.

After numerous modifications, a final version of the plan, elaborated by two different architects (Romeu and Porcell) was passed by the council in 1917. Although the detailed projects were severely distorted, the main idea and the logic of the plan remained. The foundations for the further expansion of the city were laid.

53 Quoted in Martorell, et al, 1960
54 Ibid, p.44

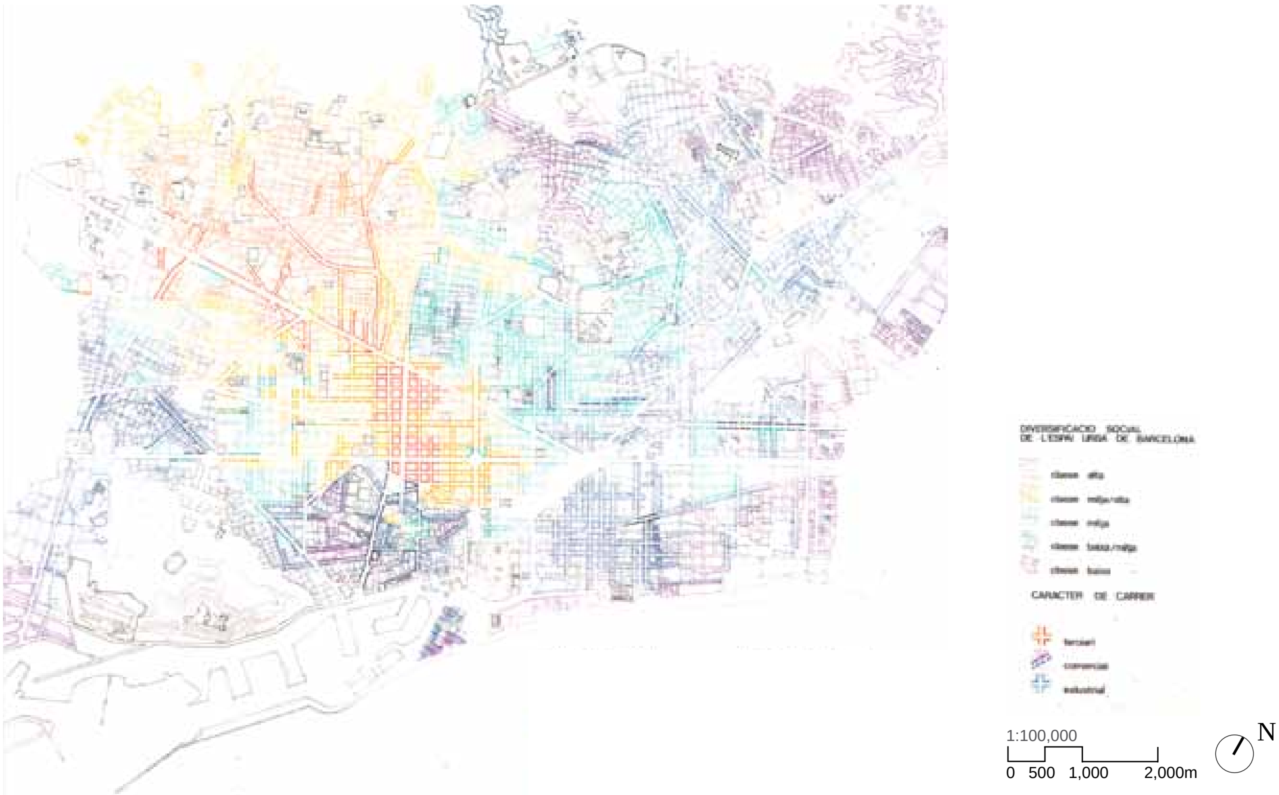


Fig.9-41 Social structure in Barcelona around the mid 20th century (source: VVAA,1994)

9.8 From Plan Macià to "Porciolismo"

The demographic growth that was initiated in the 19h century remained during the first half of the 20th. Barcelona was the main employment center in the country[55] and the city reached one million habitants in 1930. However, the continuous migration flow and the inability to provide proper accommodation brought about important problems of health and hygiene. The city absorbed the new population in three ways:

- Affordable housing of public initiative. The Spanish government had passed an Act on Cheap Housing (Ley de Casas de Baratas) in 1921. However, social housing schemes were insufficient.
- Densification of the existing urban fabric. Family flats were divided or rented so that they fitted more than one family. The living conditions were very poor as some rooms lacked windows. Densification could be also achieved by the addition of further levels on top of the existing structure.
- Shanty towns emerged around the industrial centers (Sants, Sant Andreu, Poblenou). They were formed by a type of shack named "barracks" (barracas) made of poor materials and weak construction, sometimes they were built on natural torrents, which made them vulnerable to flooding[56].

Living conditions and densification were two of the main concerns of GATCPAC[57], an association with close ties with the Le Corbusier and the Modern Movement, whose principles would be applied on their plan for Barcelona. The Macià Plan was prepared in the early 1930s, soon before the Spanish Civil war, by the GATCPAC in collaboration with Le Corbusier. Its major aim was to implement the functional zoning advocated by modern planning as the solution for the problems of the industrial city. The plan could be seen as almost utopian, although some of the ideas inspired subsequent planning decisions. It addressed the overcrowding in the existing city by the massive reconstruction in the old quarters, especially in the Gothic quarter and Raval. The main industrial zone would be located behind Montjuic, on the Llobregat estuary. The river would be channeled on that area to reduce the risk of flooding. The Eixample was respected by a larger open block type was proposed for those areas where its construction had not taken place yet.

The Civil War caused the dissolution of the GATCPAC

55 Sobrequés i Callicó, 2008 p.224

56 See Busquets, 1999

57 Grupo de Artistas y Técnicos Catalanes para la Promoción de la Arquitectura Contemporánea (Catalonian Artists and Technicians Group for the Promotion of Contemporary Architecture)

Fig.9-42 The forms of urban growth in the suburbs of Barcelona (after Busquets & Parcerisa, 1983)

c.1990

Urbanized Area:
31,281 ha

Population:
4,300,000

Density:
137 ppha

Fig.9-44 Urban form at Can Vilalba urbanization, Abrera. Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

Fig.9-43 Barcelona Metropolitan Area c.1990

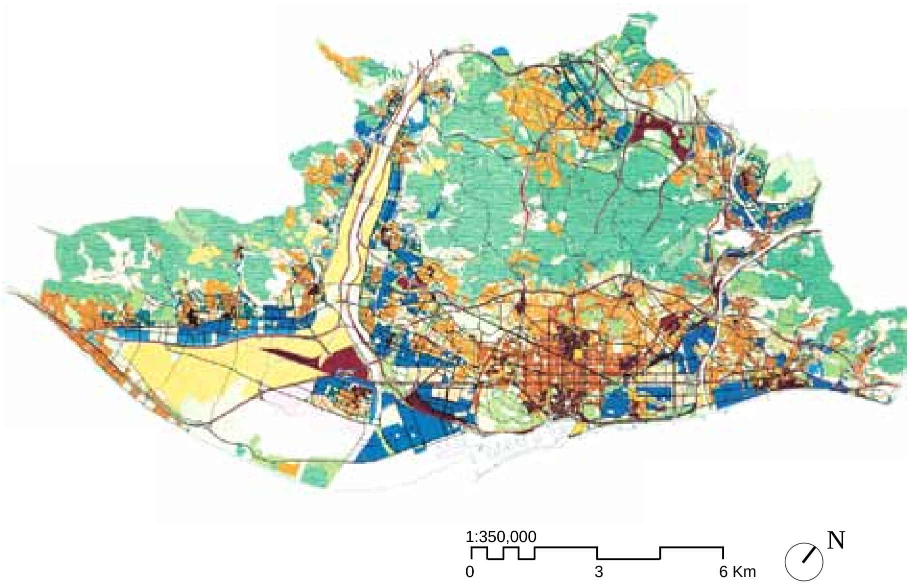


Fig.9-45 Land use plan from the General Metropolitan Plan 1974 (Ajuntament de Barcelona)

Fig.9-46 Plan Macià 1934, zoning scheme (GATCPAC, reproduced from Cerdá Archive)

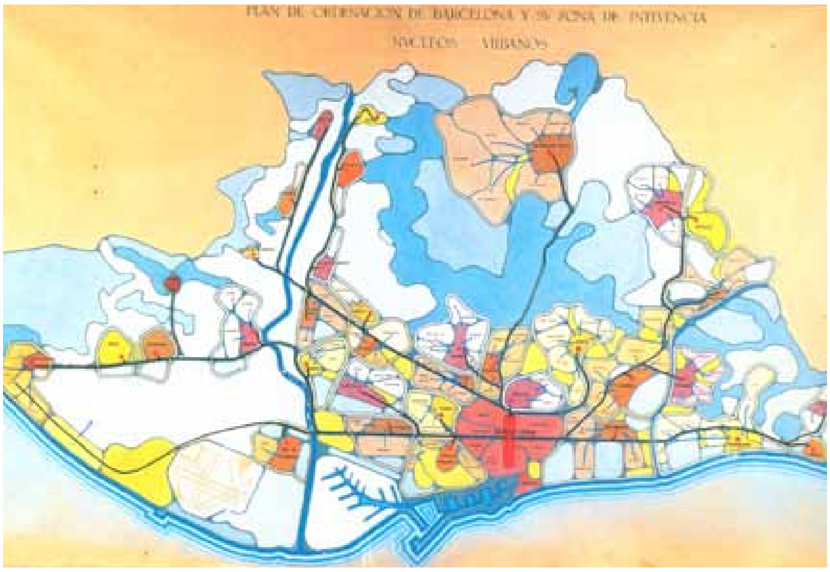


Fig.9-47 County Plan, 1953 (Josep Soteras, Pedro Bidagor, reproduced from VVAA, 1994)

and a change of regime that would sink Spain in a long period of depression and isolation. The absence of democracy had deep consequences in the fabric of Spanish cities, as planning decisions were taken from the patronage system rather than from legitimate representatives of the public interest. The problem was not so much in the elaboration of plans as in planning control. Indeed, the first comprehensive Town and Planning Act was passed in 1956 (Ley de Régimen de Suelo y Ordenación Urbana). It introduced substantial modifications in the Civil and Administrative Law regarding the distribution of competences between the central government and local authorities in terms of planning. Moreover, it included a comprehensive planning code, from conception to actual execution[58]. During this period Several plans were produced to regulate the urban growth of Barcelona. Some of them were prepared before the Town and Planning Act and most had a regional scope:

- **Provincial Plan (1945-1963**). A provincial commission was created in 1945 to formulate the General Development Plan of the Province of Barcelona. It responded to the need for coordinated planning in the main cities and surrounding territories. The plan aimed to readdress the excess immigration from the capital to other zones of the province. It was hoped that this decentralization would, at the same time, alleviate pressure on Barcelona and activate the economy of less developed zones. For this purposes, priority areas were designated to allocate industry and residents. Local town plans would need to observe the prescriptions established by the provincial plan.

- **The County Plan (1947-1953).** The accelerated growth of the shanty towns, urban overcrowding and suburban sprawl impelled the urgent elaboration of a specific planning document for Barcelona and its environs, even before the process of the provincial plan was over. Although it was drawn up by the planners of the city of Barcelona[59], the plan extends to other municipalities. The delimitation of the area has no apparent criteria other than the proximity to the capital[60]. The plan analyzed the urban continuum that was spilling over the landscape and identified a constellation of towns that should absorb future urban growth and hence mitigate sprawl. This concept was graphically expressed by several organic diagrams, similar to the social and functional analysis made by Ling and Johnson for the Abercrombie's County of London Plan. The new centers were classified according to urban models and related architectural typologies (extension, garden city or suburb) in a first attempt to "codify the relation between architectural typologies and forms of urban organization"[61]. Following prevailing urban theory, the plan prescribed the separation between industry and residence. Zoning would be complemented with prescriptions for volume and function that were allowed in each area. New motorways were also proposed to improve the accessibility and to alleviate the congestion derived from high overcrowding and increase of car ownership. The plan was developed in the form of partial plans which often diverged from the general prescriptions, typically to satisfy economic expectations of landowners and developers by increasing maximum density.

58 Martorell et al, 1970

59 With collaboratio of Pedro Bidagor, later chief of the Department of Urbanism of the National Government. Although some publications attribute the authorship of the plan to Bidagor and Josep Soteras, Martorell et al made an explicit mention of its collective character

60 Galera et al, 1982

61 Ferrer, 1996

c.2006

Urbanized Area:
34,581 ha

Population:
4,841,365

Density:
140 ppha

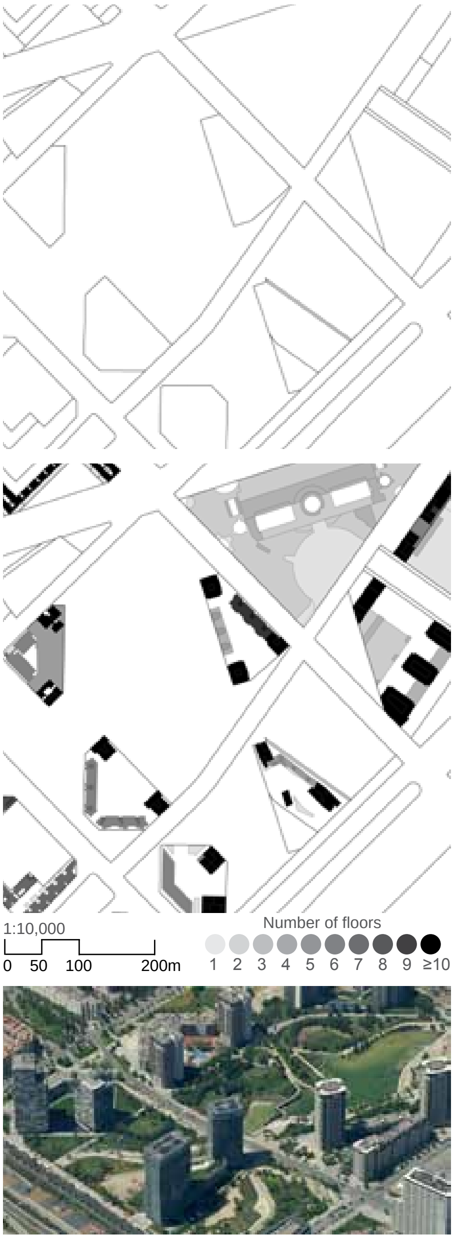


Fig.9-49 Urban form at Diagonal Mar Top: **plots**. Center: **buildings**. Bottom: **aereal image** (photo from Bing Maps)

Fig.9-48 Barcelona Metropolitan Area c.1990

1:250,000
0 3 6 Km

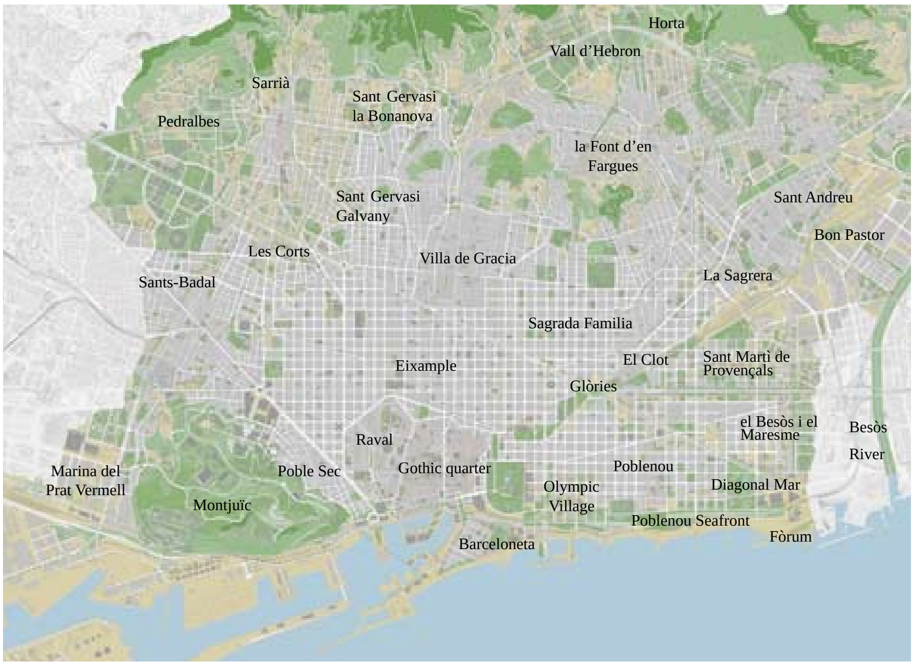


Fig.9-50 The city of Barcelona, 2012 (Ajuntament Barcelona, IBC Cartographic and Base Information)

1:100,000
0 500 1,000 2,000m
N

- **Metropolitan Area Framework Plan (1964-1968)** It was initially conceived as a revision of the 1953 County Plan but as it went beyond its geographic boundaries. The term "metropolitan" was introduced. The new definition created confrontations with local authorities and led to a delay of two years for the plan's official approval. The reality surpassed earlier predictions and the inner ring of the former County Plan proved insufficient for the relentless demographic growth. The urban realm was extending further while the centralities of the first periphery were being severely congested. In 1960 residential density in Barcelona was far beyond acceptable values (100ppha at urban centers and 20ppha in rural areas were considered the maximum limits). The Chinese quarter at Raval had over 1,000ppha, the average density of the urban center was 261ppha and the surrounding towns had already reached 115ppha[62]. The strategy was to insist with decentralization, this time over a larger territory. The new domain would extend beyond topographic barriers such as Collcerola and Montseny to include satellite towns which were within the functional zone of Barcelona but had a capacity to absorb new residents and decentralized industries. The existing towns would be complemented with new centers that were rather ambiguously defined. Territorial balance was deemed essential to construct an homogeneous urbanization. This balance was to be achieved by the wise distribution of tertiary activities. The Metropolitan Area Framework Plan had a little direct influence but it prepared the ground for the future General Metropolitan Plan of Barcelona.

- **General Metropolitan Plan (1974 -1976).** It is the main planning framework in the current city. The deep postwar economic and social crisis led Spain to technical default in the late fifties. The extreme situation forced a change in the national economic strategy, from the autarchic system towards greater liberalization and aperture to foreign investment. An Stabilization Plan was passed in 1959 to establish the new economic policies, based on monetary devaluation, deregulation and liberalization. These measures boosted national economy to unprecedented levels of growth, (up to 8%)[63], which was rather concentrated in the industrial nodes. The consequences for planning were a new wave of massive migration from rural zones and poorer regions and the consolidation of economic development as main priority. Urban plans should not obstruct the activity of such economic sectors as real estate or construction. The combination of these two factors gave birth to a period coined as "desarrollismo", characterized by over development and speculation. In Barcelona, it adopted the name "Porciolismo" or "Porcioles' Barcelona", after the mayor who ruled the city from 1957 to 1974[64]. Punctual urban improvements were possible thanks to the economic progress but strategic planning was ignored. Speculation and shortsighted decisions worsened the congestion and the imbalances of the city. At the end of his period, the city had a deficit of the most basic public facilities, and the environmental quality had been seriously degraded. The need for a regulatory plan was evident for everyone but for the mayor, who preferred a new Universal exhibition[65] to correct the excesses of two decades of urban intensification. However, the General Metropolitan Plan went on to introduce important innovations, not only for Barcelona but for planning practice as discipline[66]. The global target was, once again, to control the congestion of the central districts. It meant a drastic reduction in building density, which collided with the landowners' profit expectations. Land was systematically designated for public uses, such as green areas and facilities. A new land classification was enforced for the first time and. Apart from the traditional distinction between urban land, suitable and non suitable for development land, the notions of zones and general systems were introduced[67]. Unlike previous plans, there were no large areas of greenfield land to absorb possible urban growth. The actions had to be taken over the urbanized city, as piecemeal interventions that would gradually heal the damage of overdevelopment. The plan was defined as a "collage of different ideas"[68] and a global structure that was, to a great extent, inherited from a road network designed by the Department of Environment. It prepared the ground a new generation of plans, which would project and design the different parts of the city with great detail. It was a plan for a more democratic city that was possible thanks to the change of regime[69] and the worldwide industrial and economic crisis of the seventies. The purchase of land for the new system of public spaces could not be afforded without the industrial decay in the central city. The plan remained valid during the transformations of the eighties (Olympic Games) and it is still the current plan of Barcelona. Its flexibility to adapt to changing scenarios and different scales are among the main reason of its longevity.

62 Martorell et al, 1970
63 De Terán, 1982 p.365
64 Sobrequés i Callicó, 2008 p.251

65 Pié, 1996
66 The new Town and Country Plan was enacted in 1975 which, according to Busquets, borrows technical and operative aspects from the GMP of Barcelona (Busquets 2004, p.340)
67 Serratosa, 1996
68 Pié, 1996 p.206
69 Franco died in 1975

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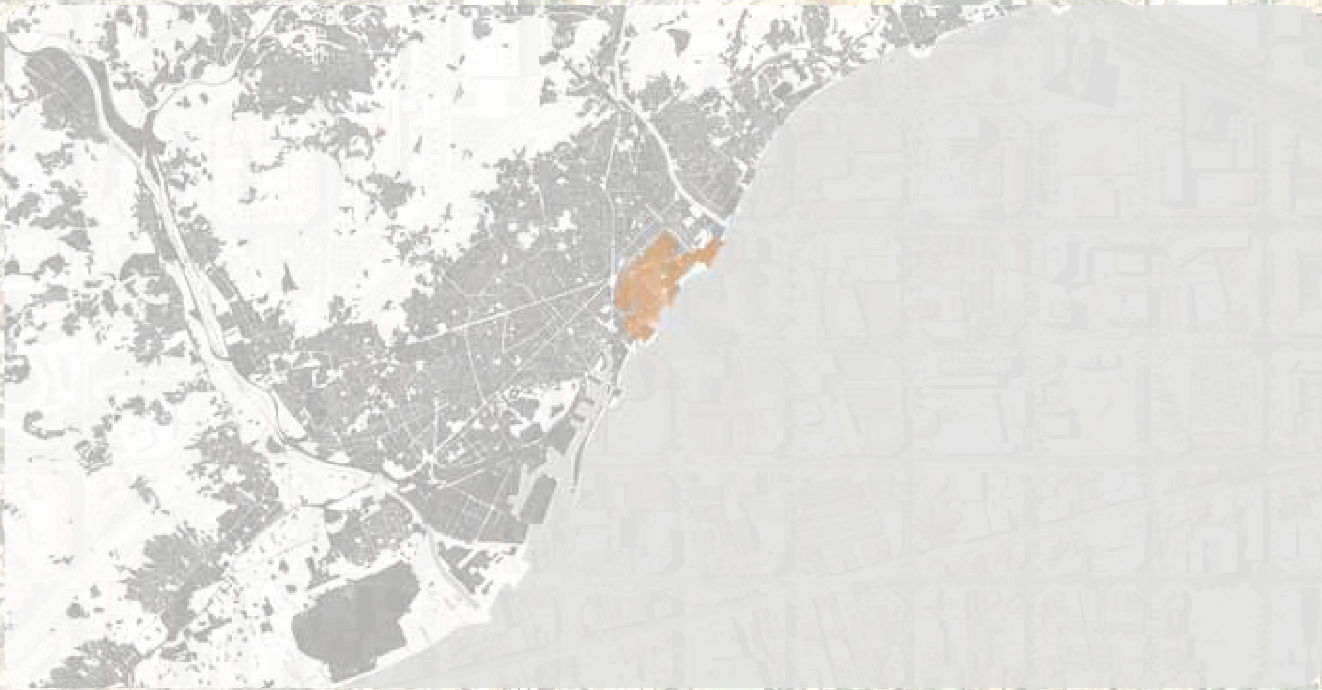
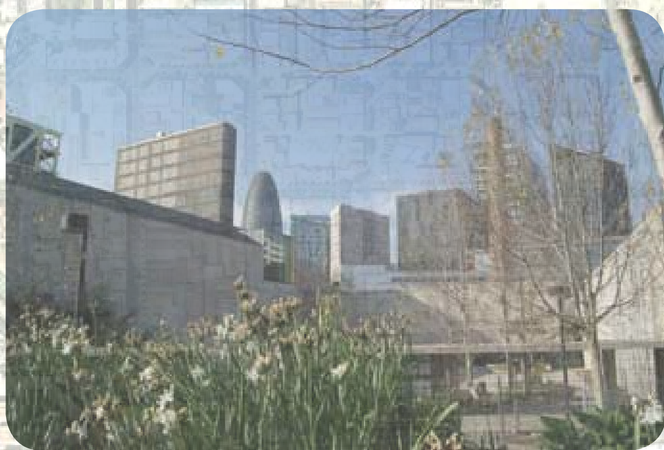


POBLENOU IN BARCELONA

POBLENOU PREEXITENT BUILDINGS



AUDIOVISUAL CAMPUS AT 22@

MAPFRE TOWER, ARTS HOTEL AND A GRAFFITI AGAINST THE 22@

CHAPTER 10

DENSIFICATION IN A POST-INDUSTRIAL COMPACT CITY: FROM POBLENOU TO 22@

A technological hub

The 22@ is the new name for a great part of the area formerly known as Poblenou. The term aims to project the future and synthesize the recent history of the neighbourhood. Where modern high-rise buildings are now standing used to be filled with factories, logistic areas, infrastructure, shanty towns and rather chaotic settlements. It was called the Manchester of Catalonia, an important enclave for the economic development of the region but also a hard place to live and work. Little of this past has remained after the comprehensive renovation that took place from the 1980s. The seafront is now a sequence of parks, beaches and a continuous promenade that goes from the Old Port to Sant Adriá. A commercial development at the Olympic Port marks the transition between the old city and the new seafront. This area transpires an American flavour. The constant presence of cars, the profusion of beach stands, the casino and international brands (McDonalds, Burger King...) do not resemble the character of a Mediterranean place. Beyond Siza's meteorological centre the definition of the public space gets dispersed. The linear park is a buffer rather than an urban room. The variable width, with very narrow sections and the regular interference of disruptive uses (parking lots, gas stations...) undermine its continuity and quality as green area. People concentrate on the beaches but deserted areas increase as we move eastwards. Urbanity has completely disappeared when reaching the Fórum, at the eastern limit of Poblenou. The contrast with the bustling Eixample is remarkable. However, it greatly improves its previous condition as the city's wasteyard.

The main field of operations lays within the polygon defined by Rambla del Prim, Gran Vía, Meridiana and the Seafront. The junction between Gran Vía, Meridian and Diagonal is an iconic entrance to the district, highlighted by the presence of the Agbar Tower. Jean Nouvels' pixelized gherkin competes with Sagrada Familia in Barcelona's skyline and as iconic symbol but, above all, it projects a cosmopolitan, modern and technological new spirit. During the industrial revolution, Barcelona had to struggle to keep its position as Mediterranean capital as it lacked raw materials and energy sources. The way the city succeeded was by adding value to import products by means of design and innovation. Similarly, the current agenda for the economic development of the area is based on knowledge and creative industries. The landscape of the Diagonal is formed by the headquarters of firms that come from technological sectors. Software development, universities, information and communication, media, design, engineering or architecture firms have replaced the traditional industrial buildings. The current perception is of place under construction. Although most buildings have been completed or retrofitted (70% was nearly completion in 2012) and over 4,000 companies have settled the forecast is to double the current number of jobs. At the same time than new jobs are created, the old activities have been marginalized by the constant threat of gentrification and the physical obsolescence of the urban fabric. The next paragraphs intend to show the main aspects of this transformation process

10.1 The evolution of the seafront

The relation between Barcelona and the sea has been historically marked by exclusion and confinement. The original Iberian port was behind Montjuïc[1] while, at the East side, only the beach and a small promontory offered protection to ships and vessels. Although the city was a prolific commercial node, the construction of the Old Port started on the 15th century. Soon, a populous neighbourhood of seamen emerged at the northeaster edge of the medieval enclosure, La Ribera neighbourhood. The construction of the Citadel in the 18th century, after Barcelona had supported the Habsburg dynasty against Bourbons in the Succession War, mutilated La Ribera and introduced a sinister barrier between the medieval precinct and the eastern coast. It would determine its subsequent isolation. The area to the east of the wall had been a marshy wetland for centuries. This past is still retained in names such as Llacuna (lake). Drying works and the Rec Comtal, the channel that brought water from the Besòs River were started in the 10th century. The place was made suitable for pasture and agriculture but also for water mills. In the seminal moments of the Industrial Revolution, when the municipality of Sant Martí de Provençals had been already formed, calico factories took advantage of the location and abundant water.

The industrialization of Sant Martí advanced considerably during the 19th century. The road to the new cemetery became the main connection with its lower part, facilitating the location of new industries. Scattered housing grew alongside factories and several settlements were already established when Cerdà conducted his preliminary surveys: La Llacuna and Poblenou[2] to the south of the road to France (currently carrer Pere IV) and Clot and Camp de l'Arpa to the north of the railway to Zaragoza (North Line)[3], one of the first railway lines that were constructed in the zone[4]. The northern railway and the Citadel were important barriers so that a great part of the area remained underdeveloped. In contrast, the coastal railway line (to France) attracted industries that could take advantage of the transport infrastructure. The demolition of the Citadel boosted a second wave of industrialization, population and housing during the last quarter of the 19th century. The number of factories increased from 57 in 1855 to 243 in 1888[5] while population doubled (26,000 inhabitants in Sant Martí[6]). The type of industries was varied: tanneries, gasworks, wine or flour warehouses, soap or wax-chandler

Fig.10-1 Poblenou seafront in 1901. The suburbs were growing with industry (reproduced from Galera, Roca & Tarragó, 1982)

1 Asensio et al, 2009

2 In some illustrations it appears as Icaria, in reference to an intent to create an utopian socialist community on that location

3 Galera, Roca & Tarragó, 1982 p.543

4 The first railway built in Spain was built in 1848 between Barcelona and Mataró and it cross Poblenou through the coast

5 Oliva, 2003

6 Ibid

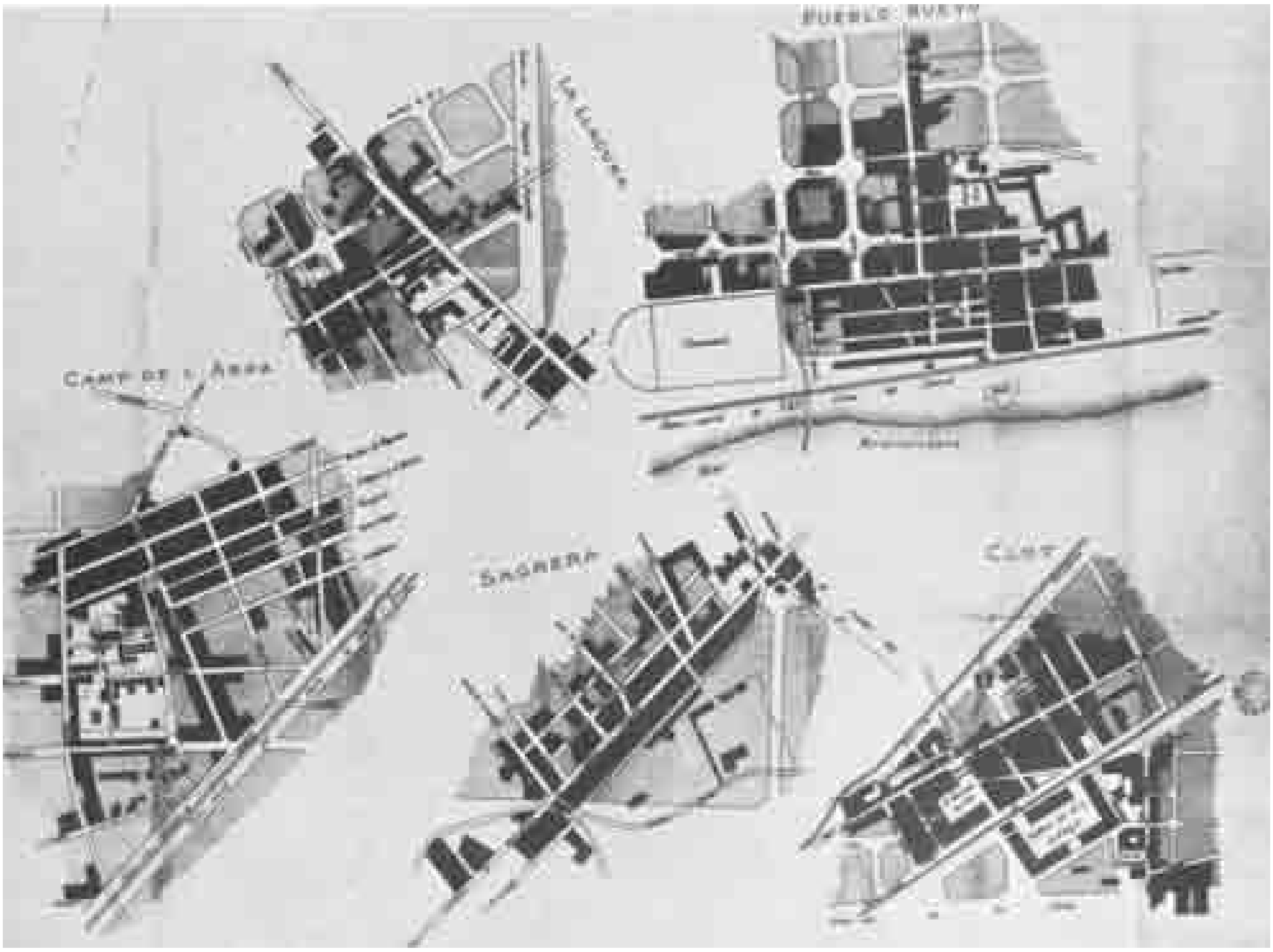


Fig.10-2 The five suburbs in Sant Martí de Provençals in 1888 (Suñol Gros, reproduced from Galera, Roca & Tarragó, 1982)

factories were located there. However, textile and metalwork were the most representative sectors. Like other industrial cities, the harsh living and working conditions encouraged the emergence of unions and associations. Poblenou was a pro-active community that frequently supported social uprisings. This dynamism persisted, in different forms (cooperatives, cultural or artistic groups) and intensity, up to present time.

The regular grid imposed by Cerdà ignored the pre-existent paths and constructions of Sant Martí, which caused the awkward overlapping of converging urban axes. In 1897, Sant Martí, together with other surrounding municipalities, was annexed to Barcelona thus becoming another neighbourhood of the rapidly expanding metropolis. The generalization of electric power during the first decades of the 20th century induced a new generation of industries, larger and more diverse. Metal, machinery, vehicles, food, chemicals...opened new factories and provided the place with its distinctive character[7]. Many of the new typologies were spatially adapted to Cerdá's block but, sometimes, they also occupied part of the street. Apart from large industries, there were smaller workshops and humble housing for workers, which lacked the most basic hygienic conditions. The poor state of housing was worsened by the neglect of the streets. Frequent epidemics, appalling mortality rates and the need to improve working conditions encouraged unionism and cooperativism. The unstoppable immigration led to the formation of shanty towns around the industrial estates: one between the cemetery and the railway line, close to Sant Adriá, known as Pekín (possibly due to Filipino families that settled there), and other one formed after the Universal Exhibition of 1888, between Barceloneta and the Gasworks, called Somorrostro. These barracks remained there for decades as they were not removed until the first years of democracy. The beach of Poblenou has been a landfill, where debris and rubbish were dumped, accumulated and burned, until very recent.

7 Ibid

Fig.10-3 The effects of a period of intense development. Left: Sant Martí in 1959. Right: the same sector in 1970 (after Martorell, Florensa & Martorell, 1970)

The neighbourhood was a main target for fascist raids during the Civil War, as it combined a marked socialist-proletarian spirit with a number of metallurgic facilities that had been adapted to produce military equipment. In the post-war, the international isolation of Franco's regime restricted export opportunities, forcing the closure of many firms while others had to split their facilities in order to rent part of the space to smaller companies. Small workshops and black market proved more resilient in the long economic recession. Although the economic scenario improved after the Stabilization Plan of 1959,[8] labour conditions were not substantially ameliorated. Workers and unions embarked active campaigns, including strikes, to demand better conditions and the regulation of minimum salary. In the seventies, the energy crisis had a devastating effect on the textile sector. A weak demand and an oversupplied market caused the closure of factories and hundreds of job losses at Poblenou. In addition, the value of the address as industrial location was being challenged by new expectations, raised by the urbanization of Meridiana and Gran Via, the partial burial of the railway and the prospects of further public investments (coastal motorway, water treatment plant...).

8 De Terán, 1982 p.365

As expected, democracy brought about important changes that affected all levels of urban life. A shift in demographic dynamics was experienced in Barcelona's metropolitan region from the early eighties. Both people and economic activities moved from the central districts to the periphery, in a process that was common to London and other European cities[9]. Better communications and the raising gentrification of the central districts fostered suburban sprawl. Unlike America, affordable accommodation was at least as important as garden city living in fostering this phenomenon. People initially moved to the suburbs looking for cheaper houses, not so much for a rural environment. Low-profile tertiary followed the relocation of industrial activities that had taken place in the previous decades. Suburban clusters of economic activity where formed, while only representation offices and strategic tertiary remained in prime locations. Many of those tertiary clusters located along the new transport corridors: C-32 at Gavá and Viladencas, A-7/B-30 at Sant Cugat and Cerdanyola del Vallés[10]. The construction of new manufacturing facilities was scarce in comparison with the

9 Font, 2007

10 The improvement of the road network was fostered by European funds, although part of the cost had to be funded by concession and toll systems

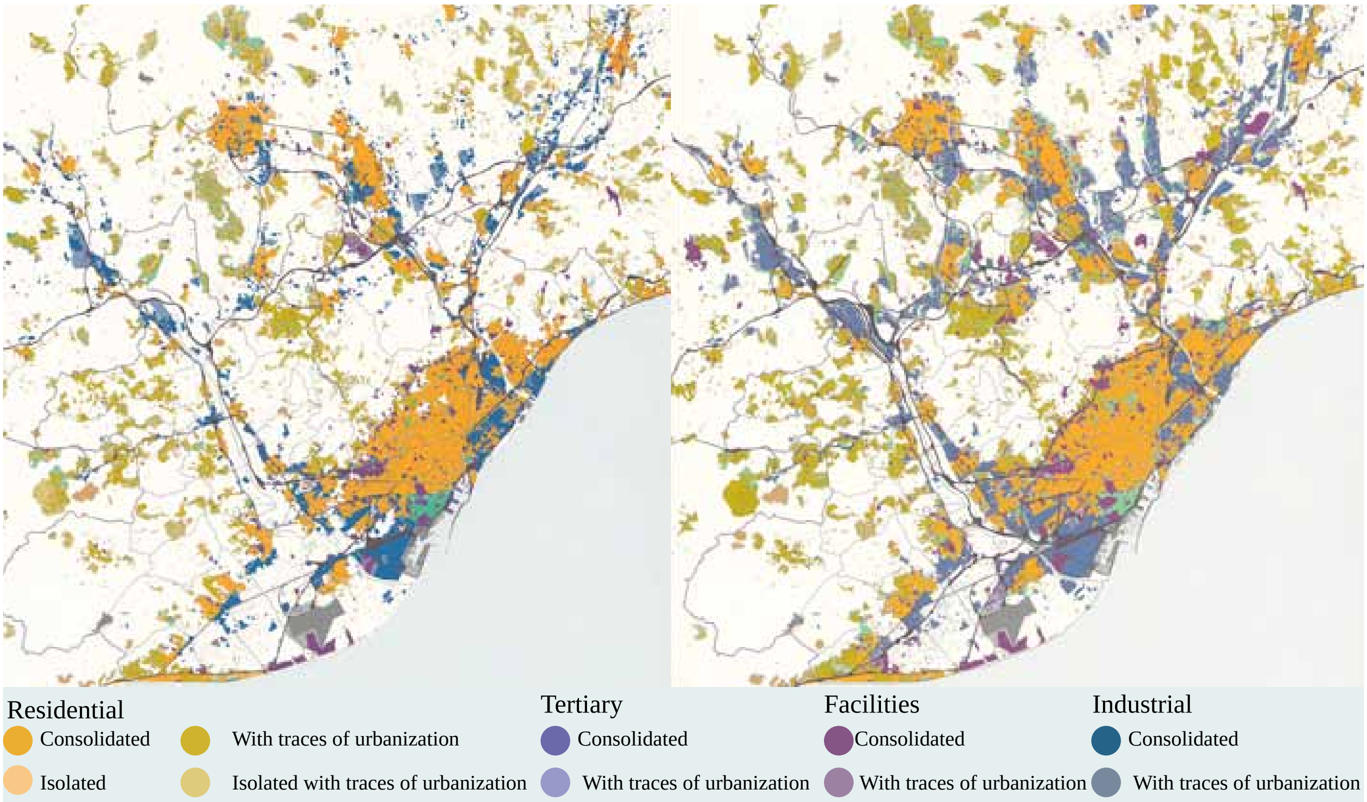


Fig.10-4 Urbanization and land use patterns. Left: 1977 Right: 2000 (source: Càtedra d'Urbanística. ETSAV/UPC-Servei d'Informació i Estudis Territorials. MMAMB, reproduced from Font, 2005)

intense industrialization of the previous period[11] and even some industrial land was transformed for tertiary purposes.

Between the years 1977 and 2000, over 20,000ha of land were urbanized in the region of Barcelona, which is a 36% increase[12]. Inside the metropolitan area, the increase was slightly lower, around 31%[13]. The traditional paradigm of compact city model was being challenged by new location patterns and economic interests. The urbanization was becoming a continuous carpet that spread over the territory in different manifestations (roads, residential developments, shopping malls, metropolitan facilities...). After the central districts were overcrowded due to "desarrollismo" of the 1970s, landscape was being *urbanalized*[14] under the universal standards of suburbanization.

10.2 The democratic city:

Rebuilding the centre, monumentalizing the periphery

The reversal of those development patterns in Barcelona and its region became one of the main objectives of the first democratic councils. Despite the poor experience of "porciolismo", urbanism had emerged as an intellectual discipline, with the involvement of renowned professionals, personalized in Oriol Bohigas, and the research undertook at the University under the lead of Manuel Solá-Morales[15]. Magazines such as UR or Arquitecturas-BIS projected these reflections to a national and international audience. The theoretical background and methodological approaches were readily available to respond to those challenges. The social context was also favorable as local associations had been active against anti-urban projects during the last years of the dictatorship.

The first two elected mayors were both socialists and economists. They mostly relied on architects the duty of urban regeneration. The first democratic mayor, Narcis Serra, appointed Bohigas as director of the Urban Planning Department who, in this way, could implement his planning ideas, which are developed in his numerous writings[16]. Bohigas was highly skeptical about the efficiency of strategic planning and he advocated for new procedures, based on direct action and targeted projects. Conventional planning was deemed as too abstract to induce any positive

11 Font, et al, 2012
12 Font, 2005
13 Ibid
14 Term coined by Francesc Muñoz in Muñoz,2008

15 Solà-Morales i Rubió, 1997
16 For instance Bohigas, 1986, for a complete list of works: http://dialnet.unirioja.es/servlet/autor?codigo=2134358 [last accessed 29.08.2013]

Fig.10-5 New Centrality Areas (Ajuntament de Barcelona,1991)

effect. Architectural projects have, in contrast, the power to transform the reality and to qualify the urban space. It was believed that piecemeal interventions, based on design, would be the seeds for a broader regeneration. The scale of intervention in Barcelona was twofold: "rebuilding the centre, monumentalizing the periphery[17]" was the slogan that synthesized the approach to solve the problems of Barcelona. On the one hand, the restoration of the inner city was to be done from the "absolute respect to the street layout and the traditional street morphology"[18]. The identity and legibility of the place had to be retained in order to ensure the identification and acceptance from local residents. The interventions were initially soft and directed to public space but there was no hesitation when shock-treatment was needed, as occurred with the demolition of entire blocks at Raval. On the other hand, the deficit of infrastructure at the urban fringe had to be balanced with a fair distribution of public investment in new facilities.

In 1984 Bohigas was replaced as head of the Urban Planning Department by Joan Busquets, another urbanist with an architectural background, who had developed his early reflections at Laboratorio de Urbanismo de Barcelona (Barcelona's Urban Lab) with Solá-Morales. The urban regeneration went on and projects became more specific. After addressing the most urgent issues (facilities and public space provision), two new plans were to provide cohesion: the **Road Plan** (1984) and the **New Centrality Areas** (1987). The former aimed to correct the traffic congestion at the Eixample and to improve access on the periphery. The idea was to prevent the use of central streets as thoroughfares, by implementing a continuous bypass. A ring with four main sections: the coast, Besós River, Collcerola and Llobregat River would be created. It would make possible a different treatment of the inner streets, which could be adapted to less intense uses (internal traffic, pedestrians ...). The Road Plan was to improve the access to parts of the city that could be seeds of urban regeneration. Busquets observed the risk of overspecialization in the Eixample, which could end up in an American model Central Business District (CBD)[19]. Rising prices were unaffordable for residents and only service firms would pay those high sums for such central locations. The Areas of New Centrality were potential places where new tertiary could be absorbed, thus alleviating the pressure on

17 Bohigas, 1986 p.47
18 Ibid, p.13
19 Busquets, 2004 p.381

the central area. They were mainly urban nodes or places where intervention was imminent or had few bureaucratic constrains. Twelve areas were identified:

- Diagonal-Sarrià
- Carrer Tarragona
- Renfe-Meridiana
- Plaça Cerdá
- Olympic Villag
- Port Vell, Glòries
- Vall d'Hebron, Sagrera
- Diagonal-Mar
- Montjuïc and
- Diagonal Pedralbes)

The transformation of these areas has determined the planning agenda of Barcelona in the last twenty five years. From the Olympics to the Forum of Cultures, or from the High Speed Station to a new techno-district, the most important projects were to take place in these zones.

10.2.1. The Barcelona Model

"Both the process and results of Barcelona's rebirth are exemplary. Though always with city-wide goals in mind, initial interventions were local and low budget, yet big in impact - not least because their design flair drew international plaudits (...) Hosting the Olympics was only part of this larger, still continuing strategy of up-grading the whole city (...)Barcelona is now more whole in every way, its fabric healed yet threaded through with new open spaces, its historic buildings refurbished yet its facilities expanded and brought up-to-the-minute. Past and present, work and play are happily intermeshed in a new totality (...) Probably nowhere else in the world are there so many recent examples of benign and appropriate attitude towards creating a civic setting for the next century"

David Rock, RIBA president at 1999
RIBA Gold Medal Award citation

The regeneration of the city attracted international attention. The winning bid for the Olympic Games was fundamental in this success, not only because it facilitated the economic feasibility of key projects, but also because it projected the city to a universal audience. However the Olympics were part of a broader strategy. It would be reductive to associate the outcomes of ten years of planning only to the Games[20]. The emphasis given to urban quality and design over quantification and technocratic studies was recognized by the architectural community with the concession of two important awards: in 1990, the Wales Prize in Urban Design given by Harvard GSD for the public space improvement programme and, the 1999 RIBA Gold Medal (the first time ever that it was awarded to a city).

Barcelona was such an exemplary regeneration[21] that the urban principles set out on the eighties became known as the "Barcelona Model"[22]. The characteristics can be extracted from the accounts of the two heads of planning during the eighties[23], although they avoided the term "model" and used "experience" instead[24]:

- The value of the urban project as the intermediate scale of intervention, between the strategic plan and the architectural project.
- A gradual change of scale, from the small intervention to larger developments and from the simple monothematic program (a square, a park) to increased complexity (mixed developments, integrating housing, streets and green areas) and from public initiative to public-private partnerships
- Urban renovation based on the characteristic strengths and weaknesses of the city. In the case of Barcelona, the opportunities were to open the city to the sea, to reclaim obsolete spaces, and to integrate marginal areas.
- The continuity of the centralities to give urban character to the periphery

Beyond the planning dimension, the Barcelona Model was also identified with social involvement and economic development. The second democratic mayor, Pasqual Maragall, sponsored a collection of reports which give detailed account of the process from diverse perspectives, such as governance, finance or cultural strategies[25].

In contrast with the international praise, critic voices pointed out the high social cost that was paid during the process[26]. The persistent reliance on large scale projects to improve the spatial fabric was detrimental to the social structure. The increasing influence of private agents derived in fewer affordable housing and a negative perception from local communities. Although the relocation of residents affected by the projects in nearby areas was a primary objective of the early interventions, the results have been neither monitored nor assessed. Recent studies have reported how local residents and small firms were forced or persuaded to move to other villages or to the periphery[27]. The loss of

20 According to Busquets, the main lines of the urban agenda were worked out from 1982, before the success of Los Angeles and far before the Games were granted (Busquets, 2004 p.394)

21 Wintour & Thorpe, 1999
22 Montaner, 1992
23 Busquets, 2004 p.351ss
Bohigas, 2004a
24 Garcia-Ramon & Albet, 2000
25 Model Barcelona. Quaderns de Gestió. 22 articles about the experience of Barcelona Urban Planning. Available at www.aulabarcelona.org/php/fcoleccio.php?id=1&sp=0 [last visited on 20.05.2013]
26 Capel, 2005 Garcia-Ramon & Albet, 2000 Casellas, 2006
27 Unió Temporal d'Escribes, 2004 p.109

architectural heritage has been another line of criticism. The lack of clear preservation criteria has been illustrated by the disposal of industrial heritage at Poblenou during the construction of the Olympic Village[28]. In other cases, historic buildings became open air museums as their urban context had been severely distorted[29]. Can Ricart, a neoclassical factory and one of the three remaining industrial complexes from the 19th century in Barcelona[30] is a paradigmatic example of both local opposition and the conflict between the scale of the preexistence and the new context.

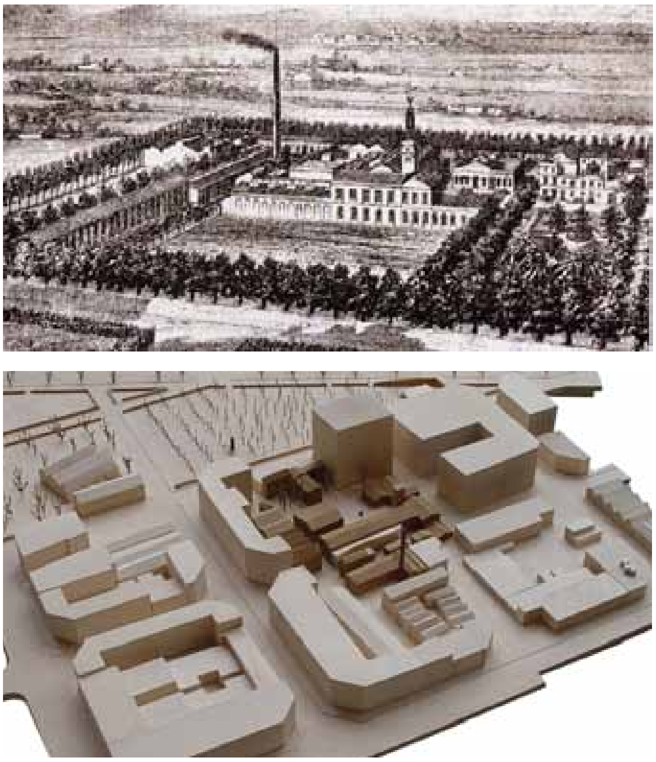


Fig.10-6 Can Ricart. Left: Original factory (Tatjer Mir, 2005) Right: Model of the refurbishment proposal by Miralles Tagliabue

10.2.2. Planning Procedures

Although it has been alleged that the intellectual debate before urban decisions was insufficient[31], the feedback between practice and theory was fluent. Perhaps it was intra-disciplinary and limited to the contact between city officials and research groups from the School of Architecture but it is undeniable that every step was supported by theoretical analysis and reported with abundant literature. The Barcelona experience was also interpreted as a laboratory for the reorientation of planning procedures, an empirical research for a different way of using planning instruments, less abstract and generic and with a greater consideration of the city's actual fabric. The loss of credit suffered by conventional planning was generalized after the poor outcomes of modern planning, voiced by Jacobs, Hall or Leon and Rob Krier. The reclamation of historical values was a common target that many European cities applied in their own way. The influence in the School of Barcelona from the schools of morphology, especially the Italian, was strong, although the emphasis was not so much on historicism as in the study on the context (topography, townscape...). Busquets argued that the limits of conventional planning had been reached and new formulations, beyond the mere analysis, were needed[32]. Despite Bohigas' reluctance on the normative constrains of the General Plan, it was eventually seen as a useful instrument. It was considered as a general framework to allow further and concrete definitions of different parts of the city. The translation from the general framework to a "culture of the urban project"[33] was made using the following planning instruments:

- **The Metropolitan General Plan.** The main proof of its eventual validity lays in its longevity. It remains in force, with numerous modifications, after almost forty years. Its scale, beyond municipal boundaries, was convenient to address large systems. After all, it had been considered a relatively progressive plan which introduced corrective measures to the excesses that landowners had obtained during "porciolismo". It established a clear definition of the public systems and the containment of urban sprawl, which was compatible with measures to make the existing fabric less dense. A metropolitan body, the Barcelona Metropolitan Corporation (CMB) was created in 1974 It had planning powers in the 27 municipalities included on it. As it happened in London, a conservative Regional Government dissolved the metropolitan agency in 1987, as it was an important counter power. However it facilitated the adoption of the plan by the first democratic corporations[34]. The endurance of the plan resides on its flexibility to be developed in partial plans, which can propose suitable solutions for each specific context.

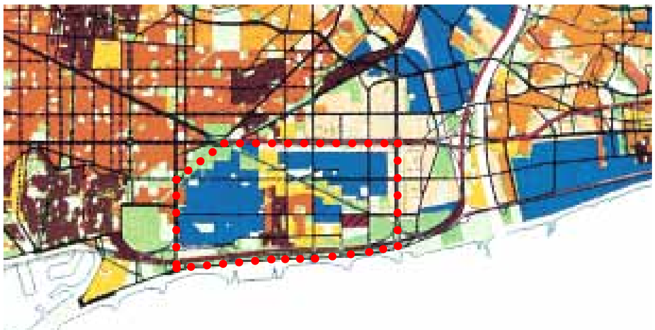


Fig.10-7 Metropolitan General Plan 1974 on Poblenou. Colour blue represents industrial uses (Ajuntament de Barcelona)

28 Montaner, 1992
29 Sabaté & Tironi, 2008a
30 Tatjer Mir, 2005
31 Montaner, 1992 Capel, 2005
32 Busquets, 2004 p.355
33 Ajuntament de Barcelona, 1983
34 Esteban i Noguera, 1999

- **The Urban Projects: the PERIs (Special Plan of Internal Reform).** The PERI is the planning instrument that enables the precise definition of urban projects within the existing city. It was introduced by the 1976 Town and Planning Act[35]. It represents the intermediate scale that improves the existing conditions of the fabric, urban quality over quantification and standards. The PERI allows the modification of general prescriptions (from the Metropolitan Plan) to the particular reality of the neighbourhood and the needs of the local community. Some of the main PERIs elaborated during the first regeneration (from 1981 until the nomination for the Games in 1986) were listed by Esteban i Noguera[36]. This list includes Raval, Gràcia, Poble Sec, el Carmel, etc...

- **The Strategic Plans of the city.** They address specific issues with citywide repercussion, strategic interventions to complement the piecemeal projects scattered over the urban domain. They could be defined as systemic as they affect the entire urban system, or structural as they provide cohesion. They were developed as advisory documents (e.g. New Centrality Areas) or, more often, as Special Plans, both thematic (e.g. Collserola, Ring roads) or sectoral (the Coast Plan, Olympic areas or Forum 2004)

Remarkably, the implementation of rather transgressor theoretical postulates upon the actual city was carried out with few and basic planning instruments: a General Plan that retained its basic concepts after 35 years and countless modifications, (it has been said that over one thousand[37]) and one main development instrument, the Special Plan (in its different versions) were sufficient to move from the culture of two-dimensional general patches to the architectural definition of the city.

One of the main challenges of urban theory during the eighties was counteract the monotonous townscape caused by standardized solutions and the disregard of the local context. Most of the strategies in Barcelona aimed to reinvigorate the inner districts, making them attractive to mitigate the migration of the middle classes to the suburbs. The still-high density was still a practical limitation, as grand projects in the style of Macià plan were unfeasible. The solution was to intervene on the few vacant lots, obsolete precincts and interstices that were found in the consolidated urban structure. As it has been described in previous paragraphs, the first regeneration projects tackled the interstices in the public domain to create new squares and green areas (the lack of urban vegetation was an standing deficit). The scale of the urban projects increased gradually[38] and the attention moved to zones that presented less resistance to transformation. Decaying industries, transport terminals, road junctions or logistic areas were suitable candidates. These opportunity areas were defined in the New Centrality Areas plan. Among the selected areas, the triangle formed by the Port Vell, the eastern edge of Diagonal Street and Les Glories junction was the most central and, possibly, the one with the biggest potential. It is mostly occupied by Poblenou neighborhood, a coastal industrial suburb that had been developed during the 19th century and absorbed by Cerdà's grid during the 20th. The relatively low density (30dpha in Poblenou compared to 66dpha in Barcelona[39]), the presence of large industrial estates at the end of their life cycle and its central condition were strong incentives for its imminent transformation. If this process was wisely managed, the positive effects could be extended to the whole city[40].

35 Ministerio de Vivienda de España, 1976
36 Esteban i Noguera, 1999 p.13
37 Esteban i Noguera, 1997
38 Esteban i Noguera, 1997

10.3 The regeneration of the seafront

10.3.1. The precedent: La Ribera Plan

In 1965 the largest industrial landowners (the national railway company RENFE, Catalana de Gas, Motor Ibérica, Maquinista, Foret, Crédito y Docks...) joined forces to put forward a plan to build a 100ha residential and commercial development at Poblenou's seafront. It was soon assumed by mayor Porcioles's council as the plan was in line with strategic policies to impulse tertiary activities[41]. The design by Antonio Bonet Castellana took the future coastal motorway, from Barceloneta to Besós, as generative axis and upper boundary. Seven roads connected the motorway with the sea while serving 500x500 meters superblocks. Buildings were elevated as the ground floor was dedicated to parking space (the flooding risk in the area was high which may have discouraged underground parking[42]). Residential and commercial uses were placed in the remaining floors. Buildings would reach up to 25 storeys. Pre-existing structures were ignored and removed from the drawings of a project that would accommodate a new population of 180.000 inhabitants[43].

The council passed the plan, under a deceptive name, trying to cover it up, in 1971. During the public consultation process it received over 8,000 allegations. The pressure exerted by local associations and professional chambers prevented its eventual implementation. The impact on local employment and the speculative character were the main arguments of the opposition[44]. Nine local associations, including the professional chambers and residents, organized a design competition to select a counterproposal that would be presented to the council. The wining team was formed by the architects and civil engineer of the Laboratorio de

39 Tironi, 2010
40 Esteban i Noguera, 2004
41 Tatjer Mir, 1973 p. 83
42 There is a connection between the reduction of industrial activity and the increase of ground water level. See Corominas, 1996
43 Tatjer Mir, 1973
44Solá Morales et al, 1974 p.3

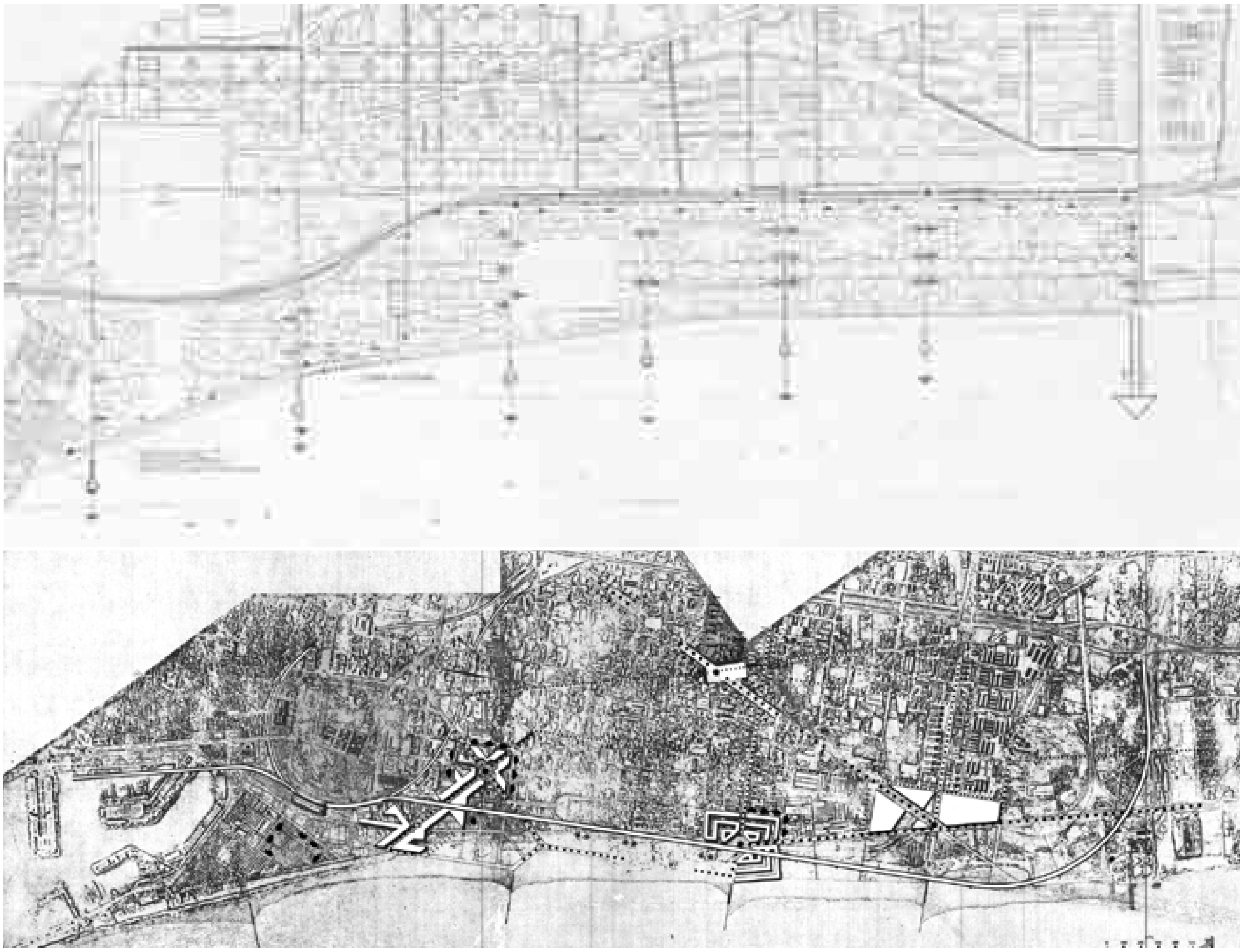


Fig.10-8 La Ribera Plan. Top: the official proposal made by Antonio Bonet Castellana for the Consortium (reproduced from Galera, Roca & Tarragó, 1982) Bottom: the alternative project by Solá Morales, Busquets, Domingo, Font and Gómez Ordoñez (Solà-Morales et al,1974)

Urbanismo de Barcelona (LUB): Manuel Solá-Morales, Miguel Domingo Cota, José Luis Gómez Ordoñez, Antonio Font and Joan Busquets[45]. They elaborated a theoretical discourse to illustrate the importance of urban morphology to understand the historic layers of the city. They explained the evolution of Barcelona as moved by capitalist forces. The area affected by La Ribera plan had acquired its industrial and labour character as a result of that urban evolution. When the bourgeoisie took the Eixample as their residence, production areas could not compete and were sent to excentric locations. A similar process would occur when the capitalist city declared the obsolescence of manufacturing facilities to transform the area into luxury apartments and office buildings. The proposal by LUB started from the unforfeitable idea that the surplus derived by planning and urban evolution must be appropriated by the public (instead of going to private hands). This could be achieved by[46]:

- Providing affordable housing for local workers
- Improving the area's accessibility
- Completing the urbanization between Poblenou and Besós, so that the latter becomes totally integrated in the city
- Introducing a metropolitan facility, a hospital, at the most central location
- Preserving the character of Barceloneta and Poblenou's historic center
- Guaranteeing the public domain on all land that was reclaimed to the sea in order to place there any public facility the city may need

45 Ibid, p.81

46 Ibid, p.61

Not without difficulties, the counterproposal and citizen's pressure succeeded and they prevented the plans of La Ribera consortium. However, the potential of the area was evident. The perception of temporality discouraged investment in industrial uses which would accelerate the decay of the zone and its buildings. The transformation would eventually take place one decade later, as part of 1992 Olympic urban strategy.

10.3.2. Regeneration stages

In terms of scale, the transformation of post-industrial Barcelona could be described as a sequential process. It started from the redesign of small squares and streets, to gradually move on to larger projects, up to strategic and regional plans at the turn of the millennium. Authors have frequently established different periods based on historical landmarks but also on the dimension of the archetypical projects[47]. The advent of democracy, the official nomination as hosts of the Olympic Games and the actual celebration of the Games are three undisputable references in Barcelona's recent timeline. The turn from the Olympic hangover to the second "renaissance" is more disputed. In any case, four distinct periods can be identified:

- **Early democracy: 1979-1986**. This period was characterized by small scale interventions on the public space of old neighbourhoods. Over 150 of these projects were undertaken. There was an strong emphasis on design. The projects were meant to amend structural deficits and revitalize their respective areas. El Moll de la Fusta, Carrer del Prim or Pegasso Park are examples of this period[48].
- **The Olympic strategy: 1986-1992**. Undergoing projects were sped up close to the deadline. The New Centrality Areas plan was adopted to construct the Olympic urban strategy. The Games required larger projects, which involved new agents for a new scale. Public-private partnerships were established to manage the urban renewal operations.
- **Post-Olympics: 1992-c.2000.** The high debt left by the Games and the poor economic situation of the country limited public initiatives. The city tried to overcome the lack of metropolitan bodies by creating Barcelona Regional in 1993. One of its main tasks was the elaboration of strategic plans[49]
- **The Digital/Smart city**: **After 2000**. Barcelona postulated as global city (worldwide scale) and it embraced the digital era enthusiastically. The Forum of Cultures in 2004 was intended to recreate the Olympic success: a new centrality was created under the umbrella of an international event. Private investment was definitely sought after and it acquired a great weight in urban decisions. It was assumed that urban interventions could influence the position of the city in global and prestigious rankings and, consequently, it would attract further investment and prosperity.

10.3.2.1. The Olympic Village

For many, the Olympics were the keystone of the city's renewal. However, the internal discourse defends that the Games were just part of a comprehensive urban programme. It was a very important part but not the only cause of the success. Certainly, the 1992 Plan was a smooth continuation, if not consolidation, of existing urban policies. Unlike other cities, such as Los Angeles or Munich, the Olympic venues were distributed over the existing urban structure, in strategic locations whose transformation could extend the positive effects to a wider area. The New Centrality Areas had pinpointed the priority regeneration zones. Four of them were selected as Olympic sites: Vall d'Hebron, the Western sector of Diagonal Avenue, Montjuïc and Poblenou. The former would be the location of the Olympic Village. The project was commissioned to Oriol Bohigas, who had recently stepped down as director of the city's Urban Department, and his partners at MBM, together with Albert Puigdomenech.

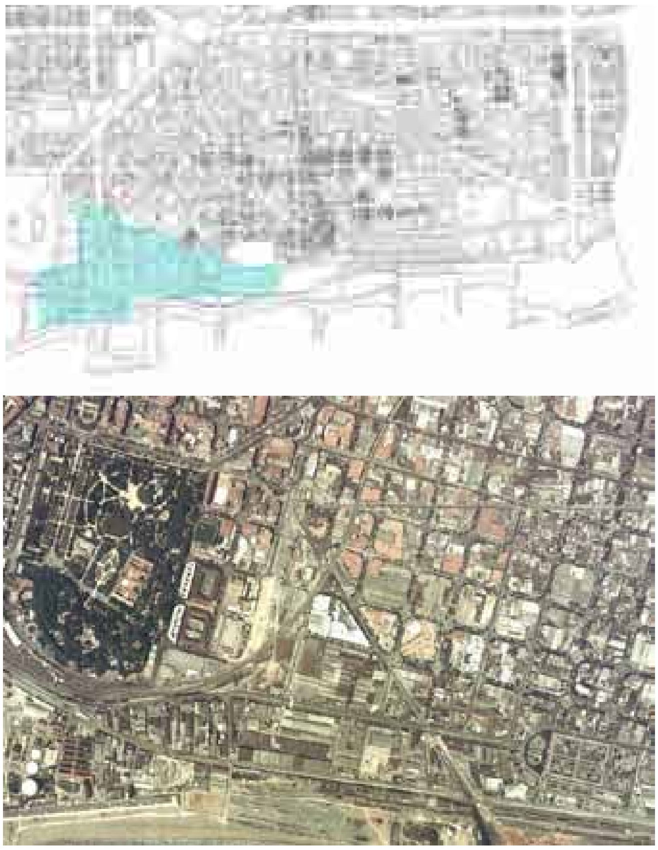


Fig.10-9 Top: Site boundaries and location. Bottom: Aerial view of the Olympic Village site in 1987 (Caballé, 1987)

47 As examples, Casellas, 2006 Sabaté & Tironi, 2008a
48 Ajuntament de Barcelona, 1983
49 Casellas, 2006

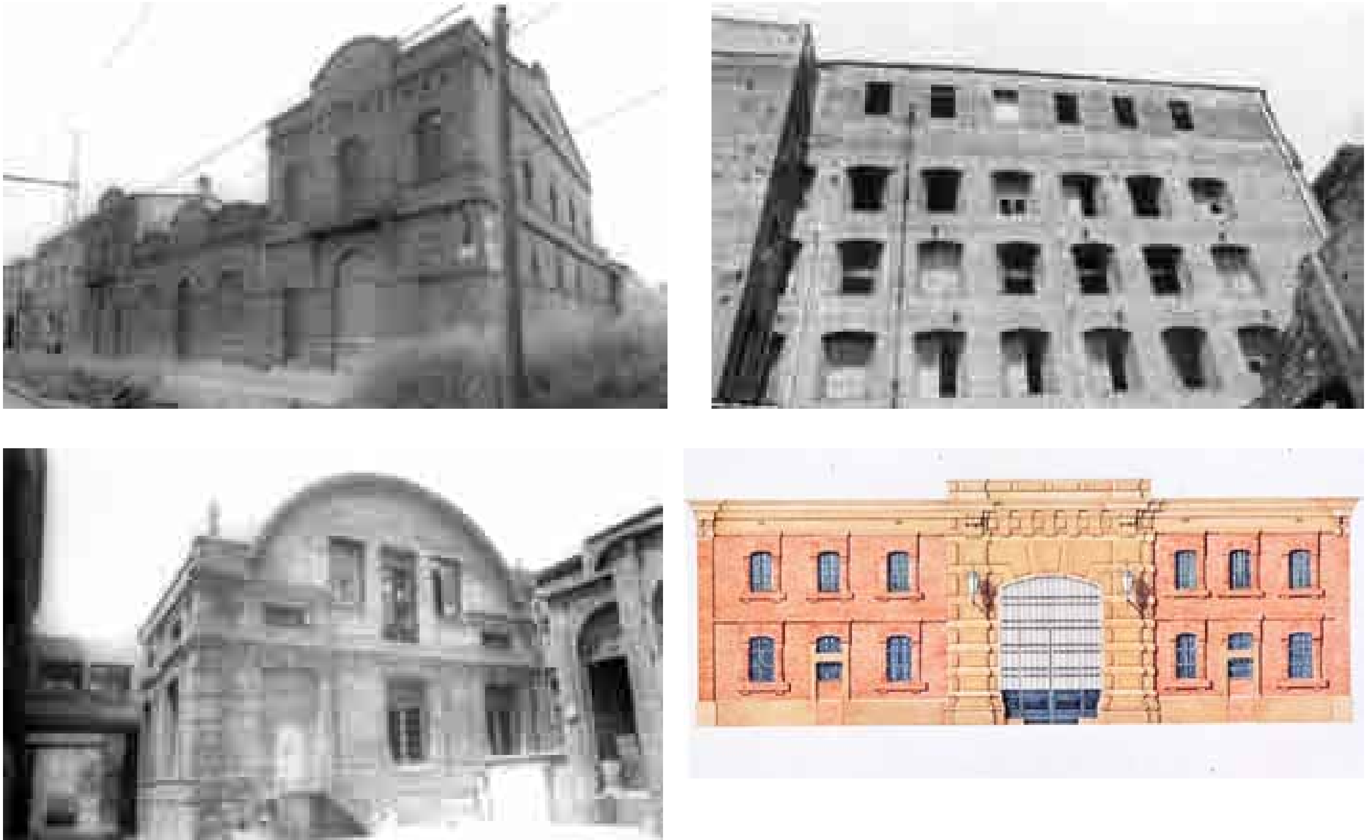


Fig.10-10 Examples of Industrial architecture that was demolished for the construction of the Olympic Village (Caballé, 2010)

Heritage

The architects described the site as “industrial triangle, practically abandoned[50]” that represented an “opportunity to open the city to the sea”[51]. Subsequently, the 55ha triangle, between the railway tracks bordering the former Citadel and Bogatell, was bulldozed and rebuilt from scratch. The loss of important examples of industrial heritage was denounced by local associations and deplored by intellectuals[52]. Moreover, it was argued that the project seemed, indeed, an slightly dulcified version of “La Ribera” plan. The fact that mayor Narcis Serra (1980-1984) was an executive advisor of La Ribera SA was politically used against it, as political was the decision of tearing all existing buildings down.[53] The council’s Heritage Protection Service proposed an extensive survey to be carried out before dismantling the neighborhood, so that historic buildings could be catalogued, photographed and drawn up. These works were included in the construction budget, thus the industrial past of the zone was preserved, if not in physical constructions (only one chimney has remained), in documents.

Planning

The diagnosis of the area according to the design team was, as illustrated above, less romantic. Their focus on the problems did not consider the integration of any of the old factories. The site was mainly characterized by its weaknesses:

- Isolation respect to the city and the sea caused by railway tracks. It represented a barrier between the city and the coastline.
- Lack of continuity in the street network as they had been taken over by large factories
- Unsuitable uses for this location: fish market transformed in car storage, water treatment plant, women’s jail, underused military barracks, shanty towns on the beaches...
- Heavy traffic, the Icaria Avenue practically worked as a motorway, lacking any urban character
- Untreated sewage was poured directly into the sea
- The Poblenou beaches were used as landfills, polluted by waste and sewage

50 Mackay, 2000
51 Martorell et al, 1991
52 Caballé, 2010 Fuchal, 1987
53 Jorba & Antich, 1983 Arranz et al, 1987

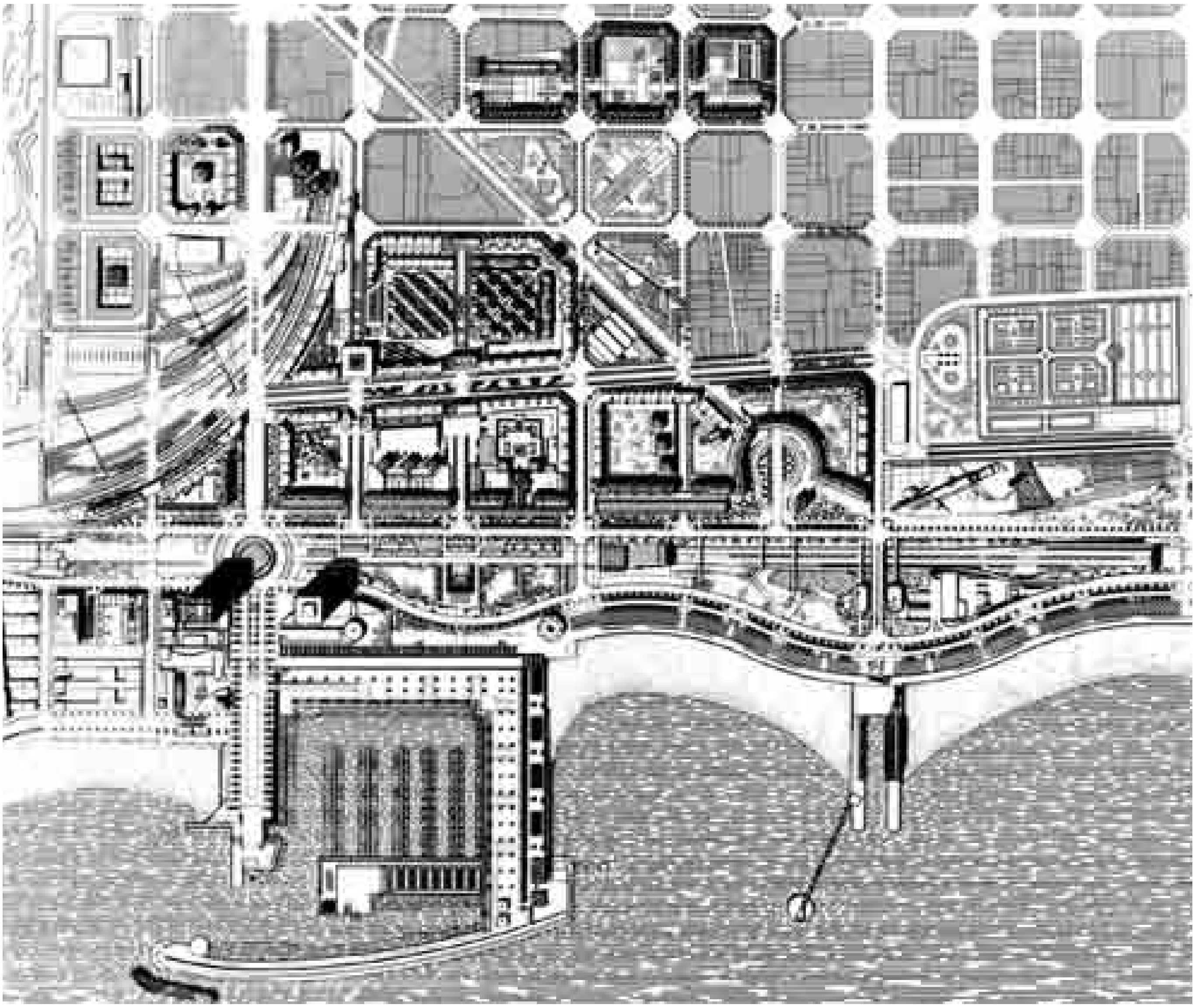


Fig.10-11 The Olympic Village project by MBM with Albert Puigdomenech (Martorell, 1991)

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Based on this diagnose, the architects came up some with a conceptual design that was summarized by the following ideas[54]:

- To rebuild the urban infrastructures which were underdeveloped, inadequate or insufficient. The beaches had to be reclaimed for leisure activities. Therefore, they had to be cleaned and replenished. Railway tracks should be buried to eliminate the main barrier. The coastal road was a critical infrastructure, as it was expected to carry a heavy traffic flow. It could well end up in a new barrier unless it was carefully designed. The sewage network was upgraded in order to respond to the requirements of the new district and the flooding problems of Poblenou.
- The new neighbourhood was conceived as a laboratory to explore new urban morphologies and housing typologies. The continuity with the city's fabric had to be enhanced by the use of traditional urban elements, such as the street, the square and the block. Contemporary architecture and modern ideals should be organically overlaid over these formal elements without denying them.
- The social and formal integration required a mixture of different uses and typologies while maintaining an overall coherence. It was hoped that the intervention of different architects in the sequential definition of the area, from the masterplan to the building level would enable an organic variation. Interestingly, the same argument as in Canary Wharf was used by the urban design team: a

54 Martorell et al, 1991

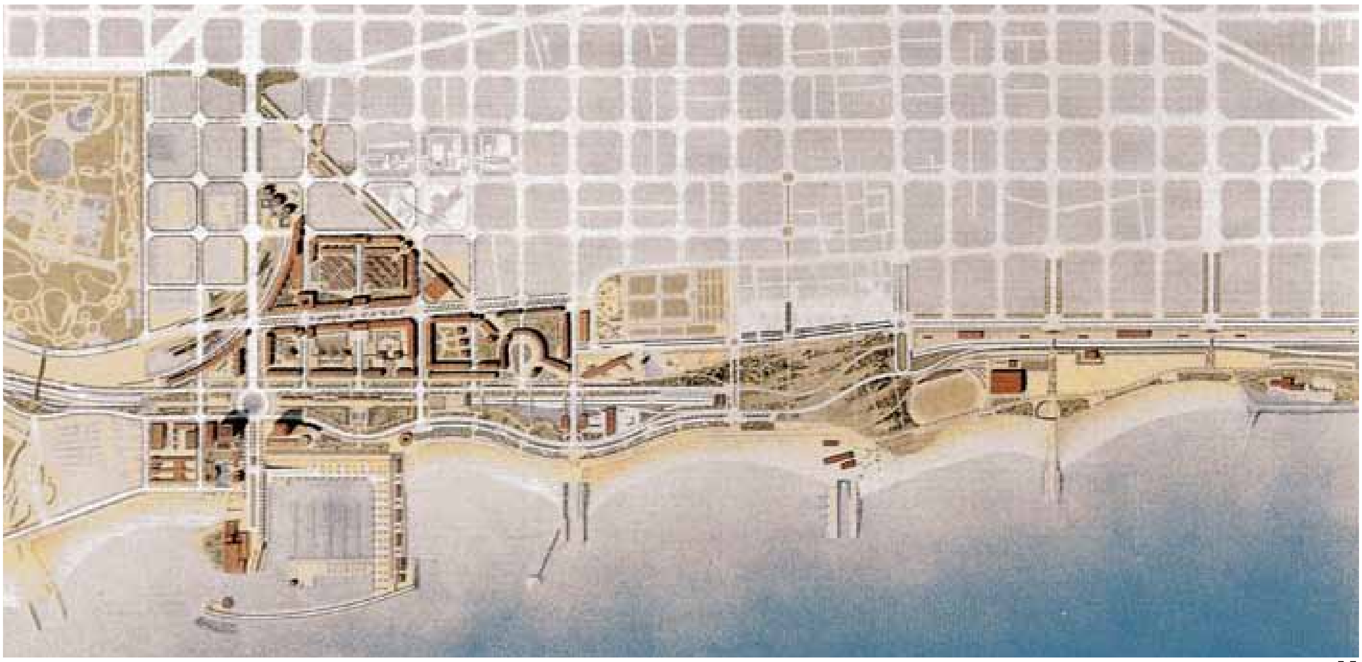

Fig.10-12 General plan of the intervention. The plan included the new ring road (partly undergorund) the marina and the linear parks system that would transform the coastline of Barcelona (Martorell, 1991)

controlled diversity of building solutions would provide a sense of gradual development as in historic cities (built over centuries) and in contraposition to speculative developments (based on repetition). The question on whether existing structures (beyond chimneys) could have provided a more truthful sense of place arises. The 1980s context, a period when residents were leaving the inner city, may explain why the reconstruction of a hygienic, open and enthusing townscape was more important than historicist preservation.

A preliminary plan was furnished with these principles and passed by the local and regional Governments in 1986. Still, it was an open framework open for discussion and debate that should be detailed in greater definition. The basic urban structure was formed by five successive urban strips, parallel to the sea:

1. The outermost strip was formed by the beaches, the breakwater system and the leisure port. Two main priorities were established in this strip: a defensive system to prevent unwanted sand removal and the sewage treatment. A sequence of open concave beaches were defined by technical criteria
2. The second strip was the 30m wide pedestrian promenade
3. The third strip would contain a number of buildings so as to introduce activities and urbanity. In order to avoid a continuous barrier, these buildings should be developed vertically rather than horizontally. The original plan proposed six towers, aligned with the isomorphic order of Cerdà's grid. However, according to Bohigas' own accounts, the director of Urban Planning in Madrid decided to reduce the number of towers to two, as it was a bad example in a moment when the first Coastal Protection Act was being prepared.[55] The two towers, occupied by a hotel and offices, have become the most visible landmarks of the Olympic legacy.
4. The fourth strip was designated for the coastal ring-road "Avenida del Litoral", as part of the city's newly upgraded transport network. It was estimated that it would absorb over 100,000 vehicles a day[56]. Such dense traffic could constitute a physical and psychological barrier to the sea and for this reason its design had to be very sensitive. The road would be partly buried but some lanes and sections were to remain overgrown so as to provide local access and urban references for drivers.
5. Finally, the fifth strip was occupied by the Olympic Village. The primary urban layout was based on Cerdà's grid and a traditional composition of block and street. However, the key idea was to combine this with the introduction of innovative residential typologies. It forced a case by case resolution of the grid modules which, in some cases were combined in superblocks.

The method of the plan is a paradigmatic example of Bohiga's project-based approach. It progressed from the general framework to the detailed development of the individual projects, public spaces and building units. The

55 Bohigas, 2004b
56 Nel·lo, 1997

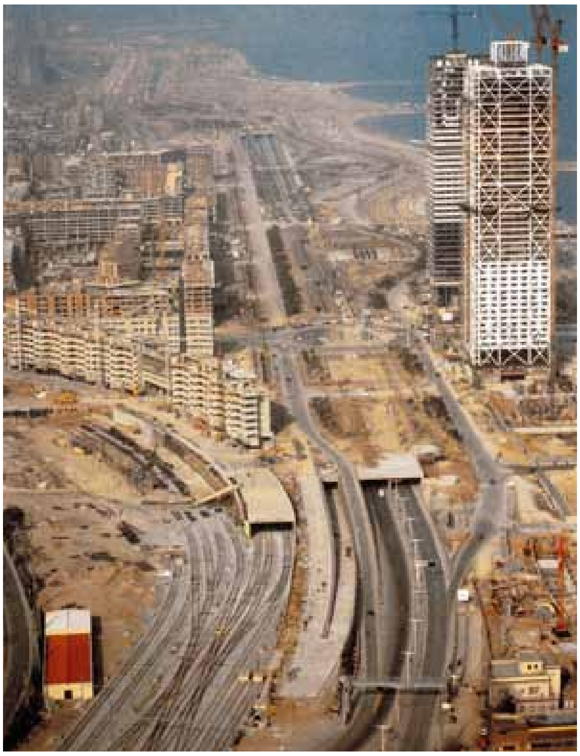

Fig.10-13 Left: the Olympic Village and urban infraestructure under construction. Right: drawing of the final proposal (Martorell, 1991)

framework was the equivalent to the Special Plan and it contained four types of documents: a design statement, a graphic conceptual diagram, an indicative sketch and a set of building regulations. Although the structural aspects were determined by these documents, some factors would admit further interpretation, especially regarding the specific formalization of buildings and public space. The second stage of the process would imply broad discussions with relevant authorities and the coordination with the design teams that were commissioned the individual projects. To this end, the area was subdivided into two levels, the super-units (blocks and superblocks) and the project units (buildings). The original planning team oversaw the project during the whole process and coordinated actions at different levels, both macro (infrastructures) and micro-scale (parks, buildings, and blocks). The main objective was to ensure the quality of the final result, overcoming the abstraction of conventional planning and the detachment between planning goals and architectural design. Public consultation remained marginal, limited to statutory requirements.

Management

If design quality was the main physical goal in Barcelona's regeneration, the main socio-economic concern was the equitable distribution of capital gains (surplus value) generated by urban transformations[57]. Public initiative was needed to ensure transparent management and to avoid speculation. Private investors were also necessary, both to assume part of the cost (and therefore the risk) and to guarantee the credibility of the operation in the market. This private-public cooperation was broadly explored in Anglo-Saxon contexts, where it was initially termed as "leverage" planning: some public sector initiates the process to create attractive conditions for private investors. The regeneration of London Docklands was, as pointed out in previous chapters, a prime example. The balance between public and private interests is critical for the successful cooperation. In Docklands, one of the main lines of criticism was the excessive public expenditure, scarce attention to social demands and the appropriation of benefits by developers.

In Barcelona, the Olympic Village Corporation (VOSA) was created in 1986[58].It was a public body with private statutes to undertake the immediate actions. It should translate the project from paper to reality. VOSA was responsible for all the preparation works, which included:

- Land purchase
- Demolition of existing structures (some 200 industrial firms and 157 housing units[59])
- Site clearance, soil and subsoil decontamination
- Reclamation of beaches
- Construction of the urban drainage system and related facilities

57 Busquets, 2004 p.411

58 Martorell et al, 1991 p. 182

59 Nel·lo, 1997

- Removal and burying of railway lines
- Construction of the new ring-road (Avenida del Litoral) and the road network
- Construction of the Olympic Port
- Construction of the public parks included in the project

Given the reluctance from larger developers to enter the scheme[60], a spin-off from VOSA was created in 1988 to oversee the construction of buildings in the Village: Nova Icària S.A. (NISA). It acquired the form of public-private partnership, with a proportion of 40-60, which restrained the influence of public interests in decision making. The capacity to negotiate the implementation of some original planning intentions was limited and the projects took a much more market oriented approach that initially intended. Innovative housing typologies were not explored as developers were averse to taking unnecessary risks. Final prices were well above market price.[61] The buildings at the seafront strip were totally funded by private developers, except those designated for public institutions. The rights to build the two towers on the seafront were acquired by Mapfre (Insurance Company) and Travelstead, the American developer who had started, and then prematurely withdrew from Canary Wharf.

The total public expenditure for the aforementioned works amounted to 500 million Euros[62] and it was funded by VOSA (65%) and various national, regional and local public bodies. A small part of the bill could be repaid directly from land sales and commercial exploitation. However, further returns were made indirectly due to the activation of large sums of private investment. The accounts in 1992 estimated the private contribution in the Olympic Village operation around 650 million Euros, almost 60% of the total[63]. Moreover, if the project is evaluated as part of overall Olympic strategy, the economic balance for the public budget would be highly positive. A recent study has estimated a net benefit by relating public investment to induced gains at year 2004. It states that, including the national insurance contributions, the surplus for the period 1986-2010 was over 10,000 million Euros[64]. According to the author, the key of the success was to allocate the greatest proportion of the investment in infrastructure (civil works, buildings) and relatively little to the actual organization of the event.

Design

Although the site was cleared from existing buildings, the masterplan design retained the fundamental elements of the historic urban layout:

- The grid of the Eixample was deformed but still recognizable.
- The three main streets were pre-existing: To the south, Carles I boulevard was extended and reinforced with the presence of the towers. The former walk to the cemetery was converted into an urban boulevard. The same use was given to the storm water channel of Bogatell, which crossed the grid diagonally and was transformed into a pedestrian street.
- The trace of the railway tracks and the Citadel can still be appreciated in the design of Carles I Park and its surrounding buildings.

The reconstruction of the seashore took its references in the extension of the grid's axes. They articulated the rhythm of the functional diagram. Activities were concentrated right off Carles I boulevard, framed by the hotel and office towers and completed by a low rise commercial development and the marina. The waterfront promenade and linear parks flow harmoniously towards Sant Adriá. The residential Village was divided into 35 building units, whose designs were commissioned to some 30 architectural firms in order to provide an organic diversity as opposed to the impersonal homogeneity of repetitive standard developments. The criteria to select the architects was rather unconventional, as there was not competition but a direct commission to firms which had been granted a FAD award[65], which excluded non Catalonian architects. To avoid the risk of an architectural theme park, some common rules were given in the planning ordinances:

- The alignments and heights were fixed. The street frontage and eaves had to be continuous. Public spaces were also delimited in the masterplan
- Façades should be made of brick. Colours and textures could vary but the use of a single material was intended to ensure the cohesion of the architectural designs. As brick was commonly used in Spanish residential developments, it would provide a common background in which singular design solutions could stand out in a controlled way. It was alleged, at some point, that it could be also taken as homage to the industrial past of the area.[66]

The design of the units was meant to represent a cutting edge laboratory of new housing typologies, exploring emerging family compositions and lifestyles. However, the recommendations from the commercial specialists at NISA were binding and there is consensus about the disappointingly

60 Mackay, 2000
61 Ibid
62 The peseta was the currency at that time
63 Martorell et al, 1991 p. 187
64 Brunet, 2011

65 Price awarded by the private institution "Foment de les Arts Decoratives" since 1958. It initially only considered candidates within Barcelona's municipality. In 1976 the scope was extended to the metropolitan area, in 1987 to Catalunya and only in 1996 to Spain and Portugal (http://arquinfad.org/)
66 Martorell et al, 1991 p. 115

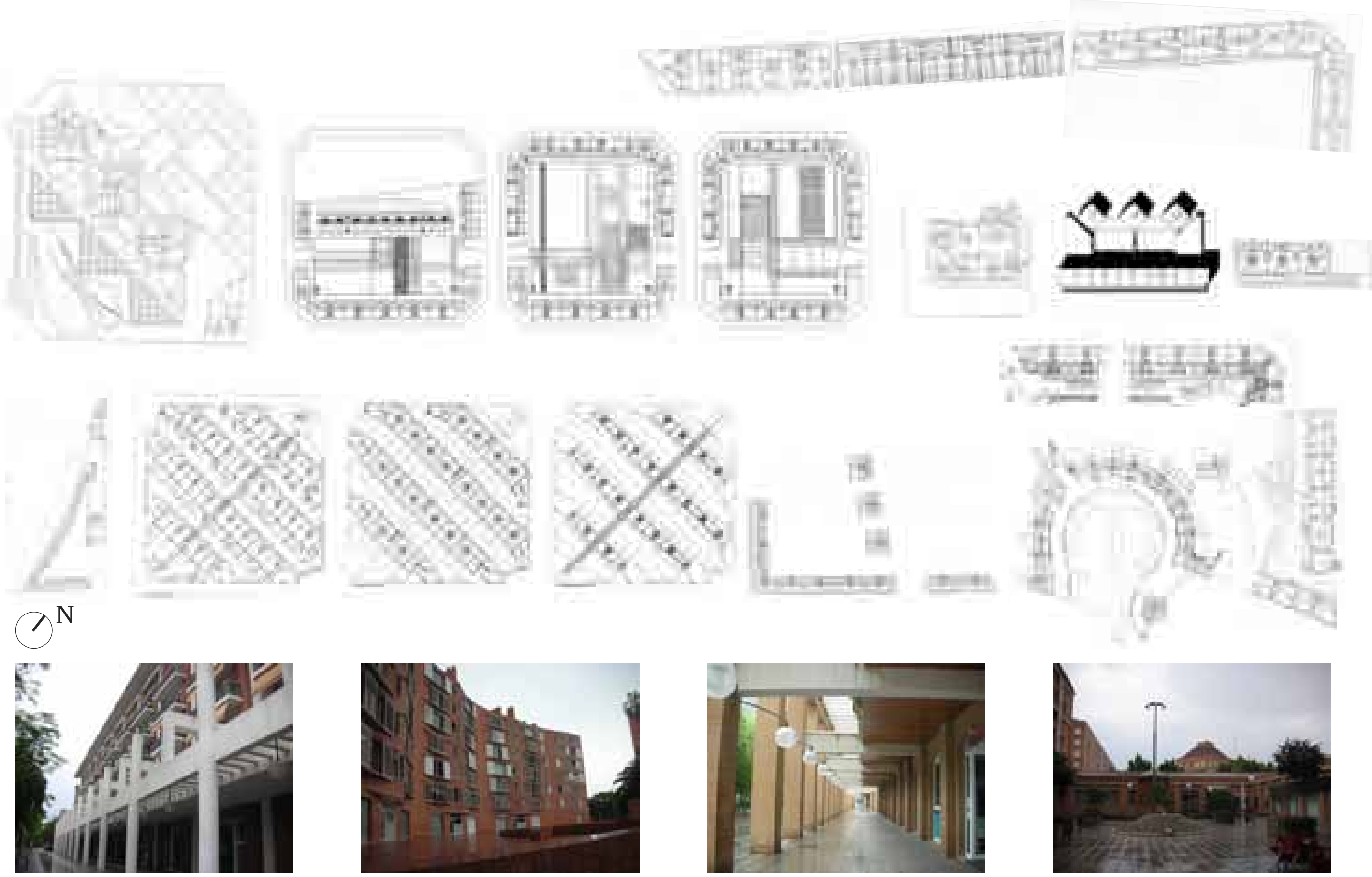

Fig.10-14 Top: Some morphological variations of the urban block explored in the Olympic Village project (after Martorell, 1991) Bottom: the built results

conventional results[67]. Martinez Alier expressed a tougher criticism as he pointed out the disregard for bioclimatic principles, which were systematically ignored in the design of the Village. He described it as:

"A plan made of Corbusierian urban principles, of tall buildings, elevated highways and destruction of historic centres. Nothing has been done in these large buildings neither in the Olympic Village housing blocks to build under bioclimatic principles, taking advantage of solar orientation to install solar collectors. There is neither waste sorting nor composting in local orchards (...). From the social perspective, housing typologies only allow for small families crammed into their apartments.[68]"

The community that settled in the 2,000 dwellings after the Games was composed of high- middle class couples, in their 30s and 40s, with children[69]. Prevailing typologies were 3-4 bedroom flats with double orientation in 4 to 6 storey buildings. Communication cores served two dwellings per floor in the linear blocks, which allows, with some exceptions and provided that high density does not prevent it, cross ventilation (an important consideration in a warm Mediterranean climate). The ground floor was typically designated as commercial units and frequently furnished with arcades. The occupation of these units took a slow pace, particularly at Carrer de Salvador Espriu (the inner side of the coastal road). The large size of the units made them rather unaffordable for the small local business. Vegetated gardens were provided in the semi open courtyards, a reminiscence of Cerdà`s proposals. Indeed, one of the project's main values could be its adherence to the Eixample's original principles, in terms of density and site coverage. If the Village is compared to any of the older blocks, the overdevelopment of the latter stands out. It necessarily translates into a different spatial quality, as David Mackay, one of the architects from MBM and resident of the Village after the Games, put it in 1999:

"is an overwhelming impression of a higher quality of living than the rest of the city in all aspects, especially the quality and quantity of light (awareness of the sky) and generosity of public space in the streets and parks[70]".

67 Most of the actors involved agreed on the missed opportunity on the Olympic Village. For instance Martorell et al, 1991 p. 115 Mackay, 2000 Nel·lo, 1997 Busquets, 2004 p. 400

68Martínez Alier, 1995

69 Mackay, 2000 p.22

70 Ibid

10.3.2 .2. Post-Olympics: 1992-2000

Construction and investment were slowed down in the aftermath of the Games. The reduction of the activity was expected but the scenario was worsened by the economic crisis suffered in the rest of the country. Given the lack of funding from public administrations, the city decided to engage on public-private partnerships more decidedly, in order to undertake pending strategic urban projects. Those included in the New Centrality Areas Plan that had not been carried out for the Olympics will be given priority at this new period, particularly those located at the East of the city (Glòries, Diagonal-Prim, Poblenou, Nou Barris). The transformation of the old industrial sectors remained as the main opportunity to upgrade the urban identity. The largest of them was at Poblenou. The most urgent deficits of the city had been corrected and the Olympic event was over .Now the local government would redouble efforts to consolidate Barcelona's brand in the global market, in a similar fashion as London or Paris were doing in Docklands and La Villette-Bercy, respectively. Consequently, the nature of the projects increased in scale, scope and ambition. Some observers described it as a second Barcelona's Model or, rather, a counter-model that went in a different direction.[71] The change of course affected multiple layers:

- Although socialists retained the council until 2011, their politics evolved towards a neoliberal model. The local authorities aimed, and succeeded, to lure private investors which, together with the poor state of public finances, ended up in developers getting a stronger position to haggle over their planning gains and reduce social objectives.
- The overall strategy was defined as a "brandification" of Barcelona[72], the fabrication of an urban image to "start and feed the process of urban production"[73]. This model understands the city as the realm of leisure and it is designed for tourists and congressmen rather than for local people. The aim was to tag the city with appealing labels, such as "sustainable", "cosmopolitan", "multicultural" or, among all, the idea of "Mediterranity"[74]. Art, gastronomy, sports and cinema have contributed to the magnification of the Mediterranean cliché. These changes can be also noticed in the council's publication, whose marketing intention is not concealed.[75]
- Architects had controlled urban planning during the eighties by means of charisma and leadership (Solá-Morales, Bohigas, Busquets) and mayoral support. The next generation did not enjoy (or manage to retain) such privileged position and their role evolved towards technocratic work and facilitators of powerful market interests[76]. Small renovation projects were being carried out but they were shadowed by the larger interventions.
- The seafront was the centre of all relevant programmes, except for some projects linked to the High Speed Train. The airport extension and new logistic area in Llobregat, the duty-free zone and new docks to the West of Montjuïc, the Old Port renovation, and the coastal section between Olympic Village and Sant Adrià del Besos concentrated most of the urban programme during the decade after the Olympics.

The new model was not introduced overnight but in a gradual sequence, in which each project was slightly larger and more radical. Due to the lengthy planning procedures derived from urban regulations, some of these projects were delayed and superseded by newer proposals, which makes difficult to date the plans with exactitude. However, four plans can illustrate the increasing scale (either physical or virtual) of the transformation of Poblenou after the experience of the Olympic Village. Three of them were already included in the PGM1976 (Metropolitan Plan) while the fourth was related to a special event.

Poblenou Seafront blocks

This project includes with two project units designated by the 1993 Modification of the PGM[77] . The aim was to define a new seafront after the disposal of the old railway tracks and the construction of the coastal ring road. More importantly, it was also meant to mitigate the lack of affordable housing in the area. The council owned almost half of the land, which it sold in public auction, with the condition that 60% of the flats had to be part of some sort of social scheme[78]. The blocks were designed by the architect Carles Ferrater after a restricted competition.[79] He described the design concept as a synthesis of Cerdà and the rational principles of GATCPAC, combining the morphology of the Eixample's grid with the linear block typology. The sea frontage is formed by a lower volume of commercial use, with a tower at the eastern corner of each block. Although this development involved the demolition of some of the largest factories of Poblenou (Catalana de Gas, Macosa, Can Girona...) the operation did not raise opposition and it was, in general, well received by the local community.[80]

71 Borja, 2010 p.173
72 Muñoz, 2008 p. 164
73 Muñoz, 2010
74 Muñoz, 2008 p.165
75 See for instance: Ajuntament de Barcelona, 1999
76 Casellas, 2006 p.76
77 Ajuntament de Barcelona , 1993a
78 Ajuntament de Barcelona, 1999
79 Ajuntament de Barcelona, 1996
80 Borja, 2010 p.98

Fig.10-15 The seafrorent blocks as in the project (inset:Ajuntament de Barcelona, 1999) and the final result (Photo:el Consorci Zona Franca Barcelona)

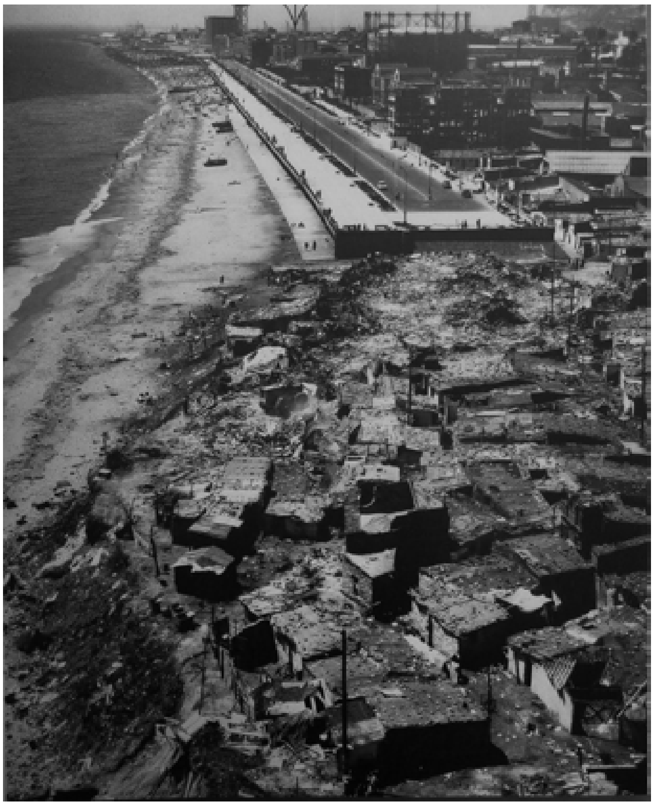

Fig.10-16 Poblenou seafront in the 1970s. Barracks at Somorrostro (source:invisiblemaps.info)

The Special Plan Diagonal-Poble Nou.

The continuity of the great Avenue that was meant to articulate the Eixample would become a reality almost 150 years after its inception. The process to connect Les Glories, the square where the Diagonal was interrupted, to the sea was activated in 1988 with an outline proposal. The Special Plan was approved in December 1992.[81]The actual construction would be delayed due to political disputes between local and regional authorities and fluctuations in the real estate market.[82] It was a complex task, since the land was occupied by a large number of small business (some 500) and housing (over 700 dwellings[83]) that had grown in anarchic manner, regardless of the Eixample layout. The local authorities were to lead the process as they had the capacity to issue compulsory purchase orders upon the existing properties, the most direct way to make the land available. Apart from the obvious benefits for mobility, the plan aimed to introduce new activities and population that could co-exist with the local community thus regenerating a degraded environment. The new urban fabric would follow the grid with a flexibility to introduce new building types. A large public park (4ha) was proposed at mid distance between Glories and the Eastern limit. The public initiative was meant to ensure social diversity by dedicating a large proportion of dwellings to compensate displaced residents and low income families. However, the project was subject of substantial modifications,

81 Ajuntament de Barcelona, 1992
82 Ricart, 1999
83 Ibid

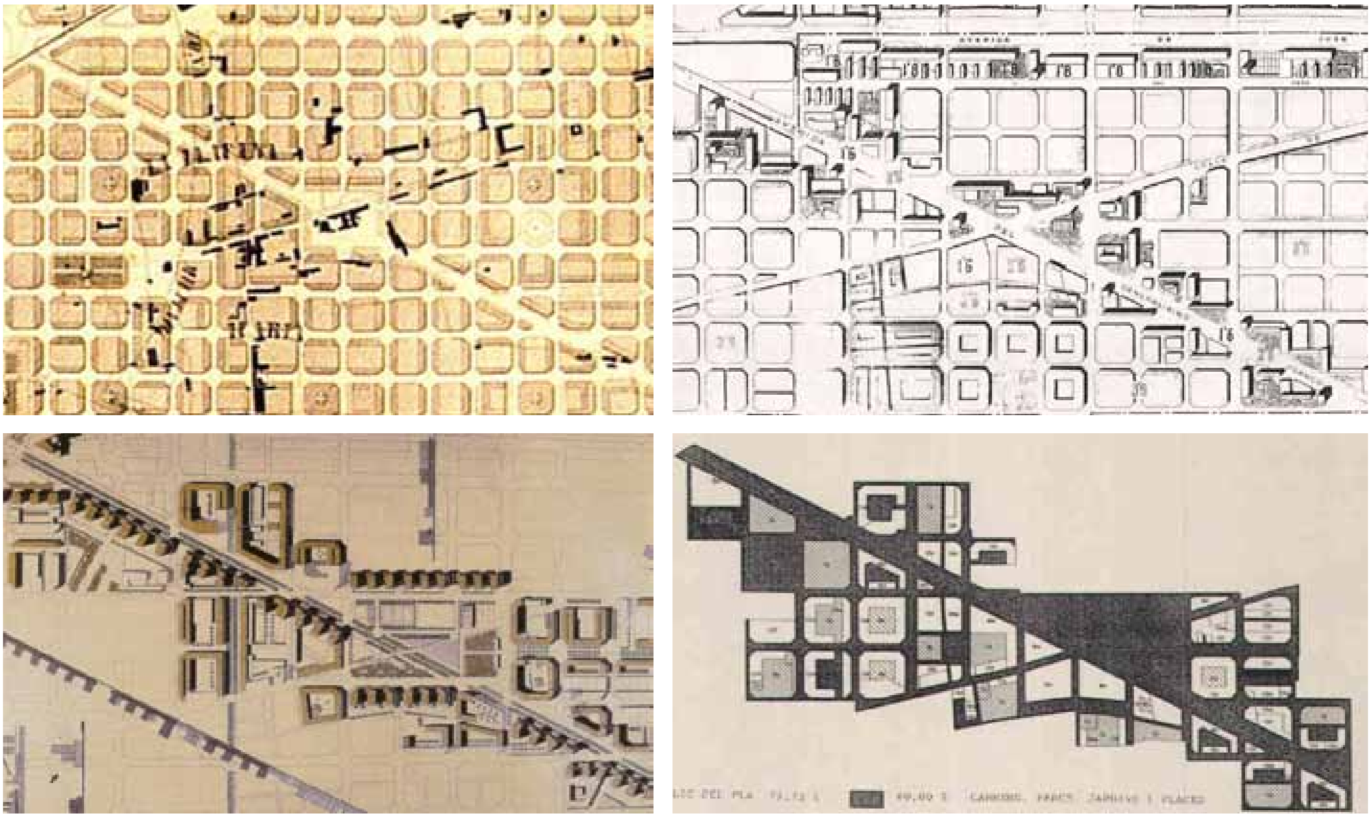

Fig.10-17 Four proposals for the Easter section of Diagonal. Cerdá, Partial Plan 1966, Outline Plan 1988 and Definitive version 1993. (Soure: 1. Cerda,1859c, 2&4. PERI Poblenou, 3.Sabaté, 2005)

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not least the reduction of social objectives, which caused the renouncement of the original planning team[84]. Small portions of the Diagonal were opened at the rhythm that the economy allowed and sustained by public investment when the market was weaker. Overall, the project involved the transformation of 65ha, 5,000 new dwellings and around one thousand million Euros of investment[85]. With the transformation of the Diagonal Avenue, the shift towards liberal urbanism became apparent in the East of the city. The emblematic street would become an icon of the indomitable social response when a poll to introduce the tram on its central section (disguised as two alternative options called Rambla and Boulevard) resulted in an overwhelming rejection that cost the mayor his re-election[86].

Diagonal-Mar

Diagonal-Mar has been one of the most heavily criticized operations in the late 20th century Barcelona.[87] The area was delimited in the 1993 Modification of the PGM[88]. The partial plan was modified in 1999 and in 2001. It had been designated as a potential pole of activity, pinpointed as strategic for the city in the New Centrality Areas Plan but it eventually became a high-standing residential enclave, virtually closed and segregated from urban life. The estate extends over 35 ha between the Rambla de Prim and Carrer Selva de Mar. Although one third of the land was owned by the council, through the Olympic Holding, it did not impose social conditions on developers. The land was purchased by an American corporation (Kepro[89]) that proposed the archetypical commercial package, composed of casino and shopping centre (67,000m^2), office accommodation (221,000m^2) and luxury flats (54,000m^2), ornamented by a generous park designed by Enric Miralles. The crisis in the office real estate market sent Kepro into administration in 1995 and, after a period of uncertainty, a new American developer, Hines, stepped in 1996. The office space was reduced to accommodate more dwellings and local architects were commissioned to provide a more Mediterranean appearance to the five residential blocks, with building heights ranging from 9 to 20 storeys. The contrast between the respectful adaptation to the existing urban morphology of the adjacent Seafront blocks and the lack of reference of Diagonal Mar is remarkable. Even the public use of the park has been allegedly

84 Sabaté Bel. & Tironi Rodó, 2008b
85 Ricart, 1999
86 Cia, 2010
87 Borja, 2010 Capel,2004 Muxí, 2004
88 Ajuntament de Barcelona, 1993

89 Ricart, 1999

Fig.10-18 Synthetic plan portraying the main operations in the boundary between Barcelona and Sant Adriá. Diagonal Mar project (highlighted with a red dotted line) and Fórum (source: Ajuntament de Barcelona, 2008)

concealed by the relocation of the residential towers and the layout of semi private roads and fences that close at night[90]. The Diagonal Mar is the landmark project that defines the "counter-Barcelona Model" as totally surrendered to market initiatives, which produces banal, segregated enclaves in the antithesis of the traditional European city.

Fórum de las Culturas

The Forum project is spatially and temporally connected to Diagonal Mar and, to some extent, it was perceived as part of the same operation. It was justified by the celebration of The Universal Forum of Cultures in 2004, an event to celebrate diversity, multiculturalism, peace and sustainable development under the auspice of UNESCO. However, the real local agenda was to replicate the Olympic strategy of connecting urban transformation with a great event. Other experiences had also inspired this new municipal venture, such as the Guggenheim Bilbao, which brought about a new age of urban governance based on star architects and profusion of cultural containers[91]. The site was located at the very last section of the Diagonal with the sea, partly on Barcelona and partly on Sant Adriá councils. It was surrounded by Diagonal-Mar development to the West and a waste treatment plant to the East. Like the Poblenou, it could be defined as a decaying underdeveloped industrial area with facilities that are normally located off-the-city (power and sewage treatment plants). The development of the Forum aimed to activate latent synergies in the last corner of the seafront to extend the effects of the regeneration beyond the physical boundaries of the intervention[92]. In reality, the operation was conceived in different stages: on the one hand, the area where the Forum took place (with the conference centre, the Forum building, the hotel and the marina) and, on the other hand, adjacent urban projects (University Campus, Marine Zoo, or the renovation of La Mina neighbourhood) that were to benefit from the added value introduced by the former, although many of them remain unfinished.

The Forum was controversial from its inception. The lack of references from previous editions and a vague program favoured its perception as a mere urban renewal. The event was then considered as a means to an end and the connection with speculative manoeuvres was established by the media and public opinion early on[93]. The clamour against the Forum was gradually engendered from the social actors of the local sphere. The arguments were directed both to the nature of

90 Muxí, 2004

91 This is a well known topic and examples can be found in almost all major Spanish cities (City of Arts in Valencia, Caixaforum or Reina Sofia in Madrid, City of Culture in Santiago...)

92 Ajuntament de Barcelona, 2008

93 Paül i Agustí, 2007

the event and the urban approach. The former was accused of posing an elitist and patronizing attitude upon developing countries. The whole event was, moreover, considered as an hypocritical image campaign for multinational corporations that had a dubious background of environmental abuse and human exploitation[94]. Regarding the physical transformation, critics denounced the servitude of urban design as a mere marketing instrument to project Barcelona's brand, while the real needs of citizens were being overlooked[95]. The urban programme was too focused on producing appealing attractions for a determined social group (tourists, yuppies and investors). The adoption of estrange and banal architectural typologies (repeated from Miami to Dubai or Panama) were not assumed by the population and they failed to create urbanity after the event. Overspecialization and the lack of a sound urban concept to articulate the intervention, beyond the hackneyed argument of opening the city to the sea, were, according to Muñoz the fundamental flaws of the urban project at the Forum[96].

However, not all critics were negative. The integration of urban utilities (power and treatment plants) in the urban fabric was considered an important lesson for the future development of cities[97]. It prevents the externalization of environmental impacts generated by urban activity. On the other hand, the consortium that coordinated the works, Consorci del Besòs, has undertaken important urban and environmental regeneration projects in a 1,134 ha around the rivers Besòs estuary[98].

Overall, the Forum is the culmination of a new model, based on private enterprise, fragmented enclaves made of self-referred architectural icons that fail to create a genuine sense of place.

10.3.2.3. The digital neighboorhood:22@district

It has been alleged that the first Barcelona model was obsessed with design[99]. The second model, conceived in the late nineties, could be characterised as the age of urban marketing and rankings. Technological creativity and its related nomenclature was the new motto of a new wave of urban renewal. The precedent years interventions had focused on the perimeter of Poblenou. The renovation of the seafront and the Diagonal delineated a triangle whose inner blocks would be the subject of the following transformation.

Although the deindustrialization had caused a progressive environmental degradation, the area was well connected and had numerous facilities on its vicinity (Auditorium, Catalonia National Theatre, University Pompeu Fabra...). The past improvements had triggered the expectations on the potential of the still designated as industrial land. Housing prices were rising and the prospective projects on Les Glories (Agbar Tower, Design Hub and Laminar Building) and Sant Andreu-Sagrera (Intermodal Station and associated development) confirmed the East as the most dynamic part of the city. It was somehow necessary to clarify the plans for the area, as the uncertainty could lead to an impasse where landowners would not invest in building maintenance and new business would be reluctant to settle.

Unlike the case of Docklands, local population was not decreasing. At contrary, it was growing while the rest of Barcelona was losing habitants[100]. During the ninety eighties the neighbourhood became a popular destination for artists, who were attracted by cheap rents, plenty of space and an inspiring and genuine atmosphere. They formed co-ops and transformed old factories into art studios or residential lofts (inspired by the New York Soho). One of the most notorious

Fig.10-19 Highrise development associated with the Fòrum 2004

94 VVAA, 2004
95 Ibid
96 Muñoz, 2008 p.169
97 Borja, 2010 p.101
98 Consorci del Besòs, 2012

99 Garcia-Ramon & Albet, 2000
100 Tironi, 2010

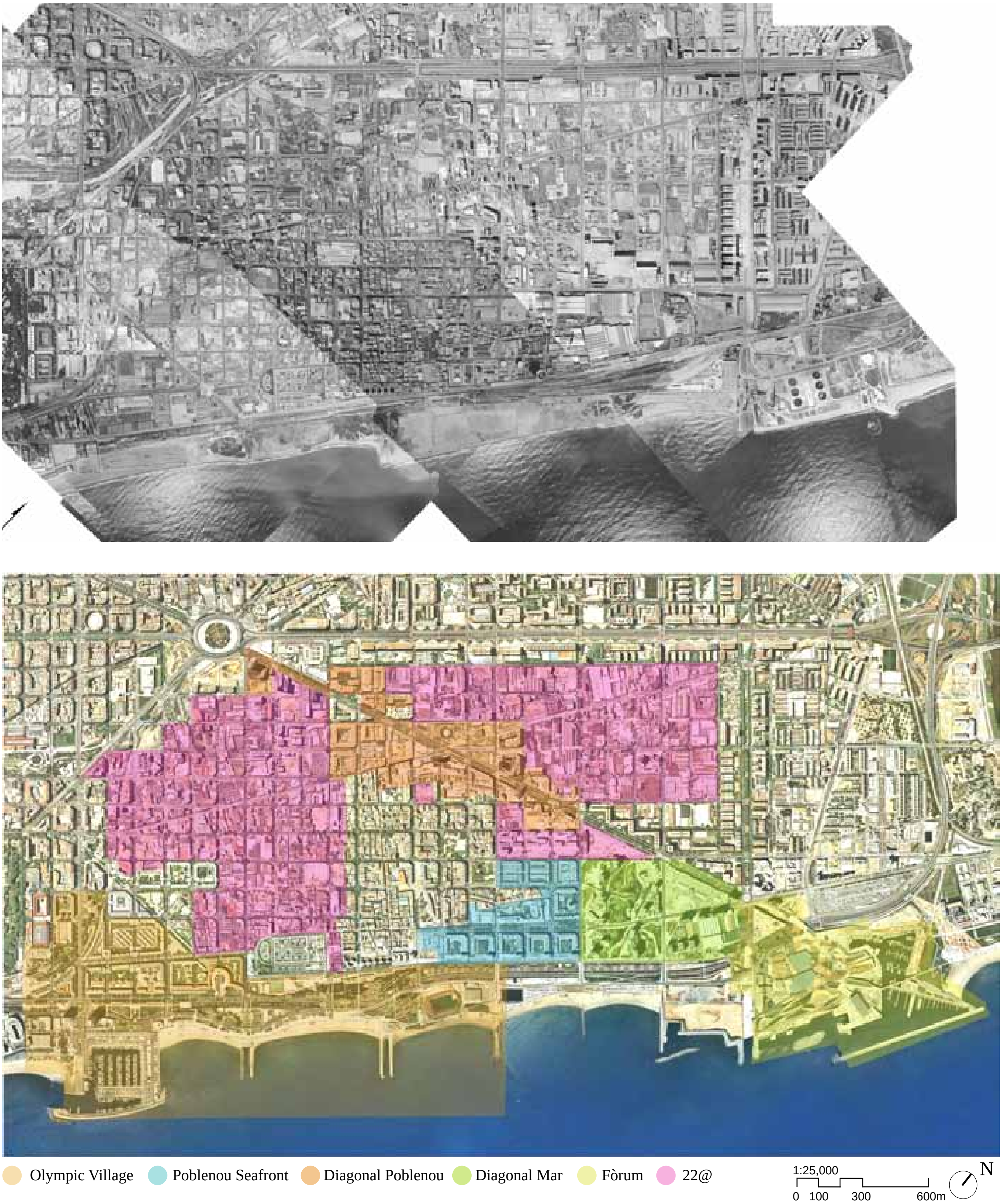


Fig.10-20 Summary of the special plans in the are of Poblenou overlaid to 1981 (top) and 2012 (bottom) orthophotos (image: Orthophoto 1981 from Catàleg de Cartografia Area Metropolitana Barcelona, Orthophoto 2012 from PNOA@Instituto Geográfico Nacional de España 2013)

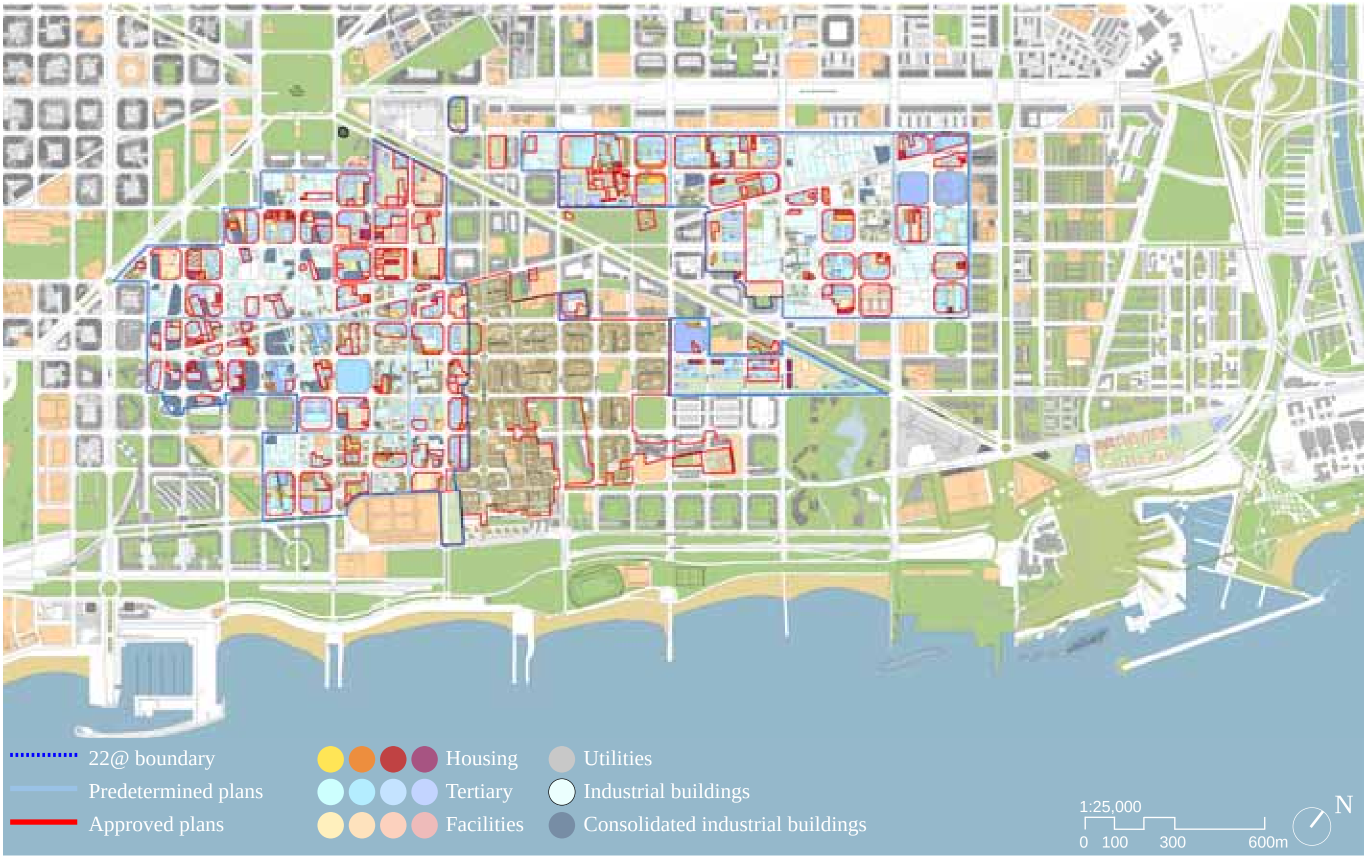


Fig.10-21 22@ general plan (after Ajuntament de Barcelona)

examples was Palo Alto, which accommodates architects and designers, such as Javier Mariscal[101]. During the nineties, the new residents at Olympic Village and Seafront induced a substantial demographic increase. There was an heterogeneous and observant community, which reacted eagerly every time they felt discriminated by the council's planning proposals.

Although the council's Urban Department was managed by a person from the previous generation of planners (Josep Acebillo, who joined the council when Bohigas was the director of the urban department) the strategy changed. The spatial and design component took a secondary role whereas priority was given to the articulation of the whole project around a common narrative, which should be assumed by the city and consumed by investors. An elaborated discourse was built on mainstream theories of social and economic sciences. Concepts and authors such as globalization (Sassen), informational development (Castells) or digital cities (Mitchell), inspired a new urban model that prioritized intelligence and communication technologies as the sector that would facilitate economic prosperity in global cities. The conceptual base was thoroughly explained in "La Ciudad Digital" (Digital City)[102], a publication that analyzes the role of ICTs on urban sustainability, with case studies from different parts of the world and an special focus on Poblenou. The case studies showed how the integration of productive activities within the urban fabric had been present in some of the most successful regenerations. Businesses could take advantage of concentration and intellectual synergies whereas the cities could benefit from the creation of job opportunities. Sillicon Valley was the paradigm of successful technopark, associated with a University (Stanford) and attractive living conditions (mild Californian climate). Further learning outcomes were extracted from Bangalore (regarding the education system), Cambridge (relation University-Business) or New York (entrepreneurship, talent concentration). The authors of the study were advisors during the planning process and the book was explicitly quoted in the official planning documents[103].

After the statutory planning procedure, the Modification of the Metropolitan Plan for the Renovation of Poblenou's Industrial Land was definitely passed on September 2000.[104] The designated area covered 200ha and 115 blocks of the Eixample, on discontinuous sectors to both sides of the

101 www.paloaltobcn.org [Last accessed 07.06.2013]

102 Barceló & Oliva, 2002
103 Ajuntament de Barcelona, 2000
104 Ibid

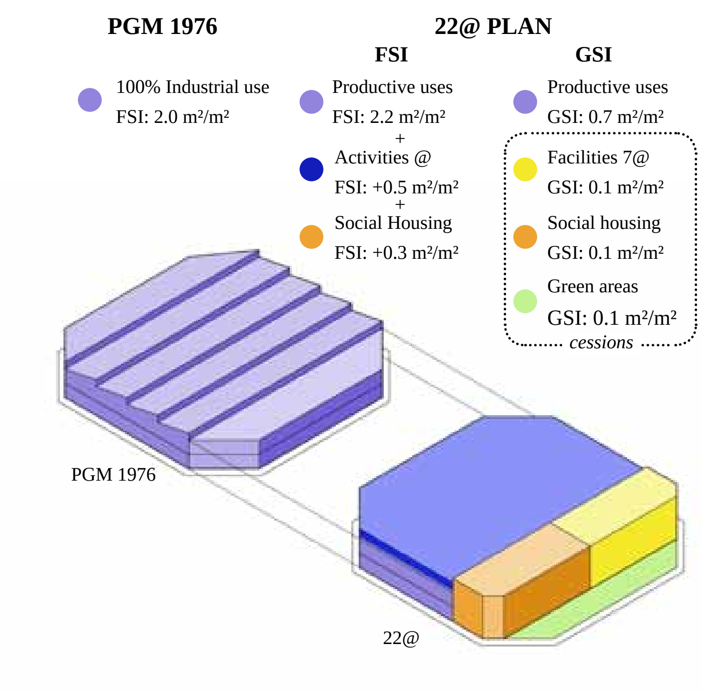


Fig.10-22 Incentives and duties for developers. Comparative between the Metropolitan General Plan and 22@ prescriptions. The new ordinances allows more density while establishing statutory cessions of land for public uses (green areas, facilities and social housing)

Diagonal Avenue. The internal reform was to be gradually developed, by means of individual operations that should be integrated into the existing fabric, thus preventing dramatic transformations of large areas. The overall objective, as stated by the plan, was to create the urban conditions to allow the introduction of new economic activities, based on emergent technologies. It was considered a project of regional scale as it was the opportunity to make the transition from manufacturing to knowledge based industrial model. This aspiration was symbolized by the nomenclature the plan used to designate land uses and gave name to the whole project. The original Metropolitan General Plan had assigned the class “22a” to industrial uses, which were the prevailing ones at Poblenou. The amendment of the plan created a new definition for the land formerly designated as 22a to establish the regeneration criteria on those zones. The new definition, coined as “22@”, would encourage the introduction of ICT activities by allowing higher Floor Space Index (FSI). The whole plan was named after this land use type as the “22@ district”, a term that would be extended to everything related with the area. A private society with public capital “22 ARROBA BCN, S.A.U” (22@bcn) was created by the council to promote and manage the regeneration process. This body was entrusted to represent the council’s interests and it would lead planning initiatives, such as public plans, infrastructure provision, design of public space, land transactions (purchase and sell), etc... It would create ad hoc partnerships with private companies for specific projects. Greater efficiency was argued as the main justification for this management system as it was expected that reduction in bureaucracy would accelerate projects.[105]

Informative leaflets summarized the specific actions to attain the plan’s objectives[106]. They explained the way in which general principles, such as density or urban sustainability, had been interpreted as statutory planning prescriptions:

Increased Floor Space Index at block scale

Due to the changes in the permitted floor space index, the net FSI could potentially increase from 2 to 3m^2/m^2 in the area. Before the renovation, Poblenou had lower density than Barcelona’s average, both in population and built up area. There was scope for further intensification. Private developers could benefit from higher FSI, provided they complied with the introduction of @activities, assumed urbanization costs and transferred part of the land to public ownership (fig. 10-22)

Mix of Uses

The plan assumed that urban complexity enhances the transmission of information and, therefore, the creation of new knowledge which, in a way, would ultimately redound to urban sustainability[107]. The monofunctional character of the neighbourhood would be replaced by a diverse district, with industries of different kind, but always compatible with urban life, facilities, housing and green areas. The following uses might coexist:

- **Industrial**, excluding transport logistics and harmful activities.
- **Offices**. It requires permission and it is only allowed via Special Plans, so that the area does not become a tertiary zone
- **Housing**. The plan recognizes the existing housing (around 4,000 units) and permits new dwellings in existing buildings without further planning procedures. In transformation operations, 0.3m^2/m^2 must be designated for affordable housing. It was expected that 4,000 new affordable dwellings would be built in the 22@ area. However, as Marrero Guillamón pointed out, the plan only determines the construction of housing on 44% of designated land, whereas the remaining 56% will be open to the discretion of private initiative[108].
- **Commercial**, except shopping malls

105 Casellas, 2006
106 López Corduente, 2012
107 Rueda Palenzuela, 1995
108 Marrero Gillamón, 2003

Fig.10-23 Public space structure (Ajuntament de Barcelona, 2008)

- **Residence**, other than housing (hotels or similar), is allowed as long as it can be considered as temporal accommodation for local workers.
- **Facilities**, to satisfy the needs of local residents (health, sport, leisure...) and an specific type of facility that is related to support research and innovation, which is termed land use type7@.
- **Public space**. The plan has programmed over 110,000 m² of green areas and it established that 10% of the former industrial land had to be designated for public use. These public spaces are based on the existing property structure, reclaiming passages or landmark elements, such as chimneys or factories. The "Rambla del Poblenou" remains as the main axis of social activity but is complemented by the newly refurbished streets that results from the public Special Plans

Knowledge-based activities

In relation with the former, not all industrial activity was to be removed, but only those which are not suitable for urban locations. Light industries and traditional activities should be allowed to enhance a "rich and diverse productive structure and to boost competitiveness"[109]. Incentives were given to those projects which ensured that, at least, 20% of the floorspace would be dedicated to "@activities". These were characterized by the intense use of information and communication technologies and qualified services. Talent was considered as a main production asset. The activities that were eligible were identified, listed and regularly updated by an advisory board[110] . They included ICT, service and knowledge centres.

Cutting edge infrastructure

The kind of activities that were proposed required a sophisticated infrastructure network. The existing services were clearly outdated and they would discourage IT companies. One of the first initiatives consisted on the implementation of an Special Infrastructure Plan to upgrade 37km of streets with advanced systems of energy, telecommunications, waste management and district heating and cooling. The cost of the urbanization would be assumed by landowners (60%), council (10%) and suppliers (30%)[111]

- **Industrial heritage.** Unlike the Olympic Village, part of the industrial heritage was to be preserved. The Village's design aimed to produce an organic character artificially. In this case the combination of old factories and traditional urban fabric with new buildings would provide it naturally. The

109 Ajuntament de Barcelona, 2008

110 Clos, 2004

111 Oliva, 2003 p.33

Fig.10-24 Location and boundaries of the six Spetial Plans of public initiave (22@bcn,2005)

Special Plan of Poblenou's Industrial Heritage Preservation was elaborated to provide protection to 114 structures. Nonetheless, controversy about the transformation on part this heritage would arise.

Flexibility

Unlike conventional plans, the physical result was not predetermined. The transformation of the district would be progressive and defined by different development plans. In this way, the scope and design of each zone can be defined in detail and adapted to its particular conditions. The plan simply determines the common rights and obligations, a general framework that would be interpreted at a lower scale. Although the minimum unit of intervention was the block, exceptions would be made for the following cases: half blocks defined by alleys, plots over 2,000m², industrial buildings with an interest, and consolidated housing frontages.

10.3.2.3.1 Management: Public Special Plans

The 2000 Modification established two types of plans: public and private. Public plans were Special Plans over pre-established zones, which were considered strategic to activate the regeneration process and to attract private interest. Those plans would share some general objectives, as stated in the 2000 Modification[112]:

- To develop sensitive areas of the Poblenou in such a way that they trigger the transformation of the district.
- To provide coherence to the urban structure of each sector, selecting and applying the most suitable planning instruments.
- To ensure diversity and mixture of uses to guarantee a minimum urban complexity. The allocation of facilities, compatible uses and green areas was considered essential.
- To provide continuity to the residential fabric, in order to facilitate a social appropriation of the street.
- To explore diverse spatial and typological models that can be exploited as a distinctive asset
- To identify and develop the specific programme of activities for each area.

The six Special Plans of public initiative covered the following areas:

1. Llacuna axis

It complements the Rambla del Poblenou by proposing a complete redesign of the zone, incorporating new facilities and public space. The initial proposals had to be reconsidered because it raised social opposition, which fought against excessive number of tall buildings

Table10-1 Llacuna land use breakdown

Llacuna	
Economic activities	170,149 m²
Facilities	51,516 m²
Green areas	16,631 m²
Affordable housing	192 units

112 Ajuntament de Barcelona, 2000

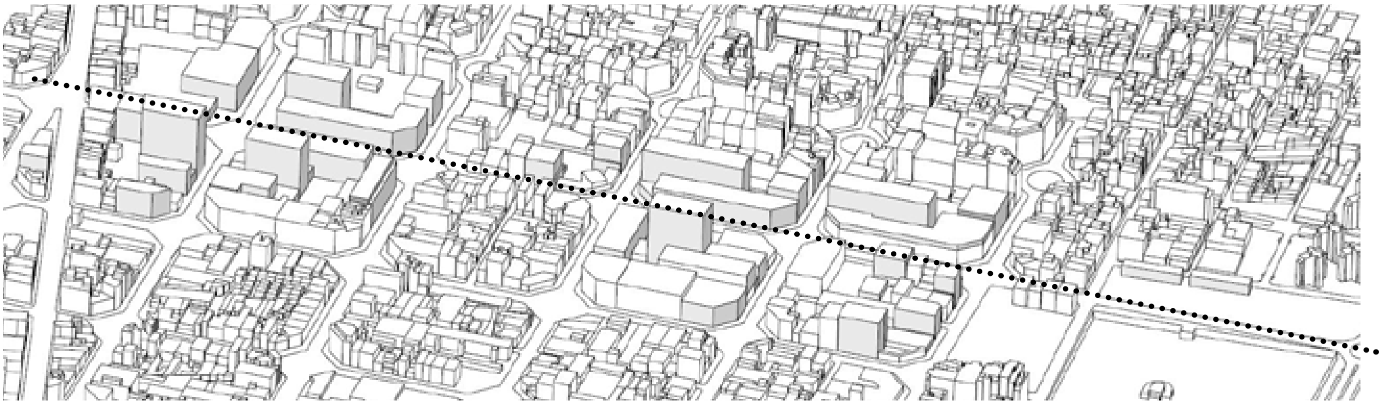


Fig.10-25 Perspective view from the special Plan for Llacuna axis (22@bcn,2011)

2. Audiovisual Campus

The aim of this sector was to generate a concentration of companies and institutions related with visual media. Taller buildings were grouped along the Diagonal Avenue in order the increase their visibility and representative character. Historic structures were retained and restored, such as the former factories Can Framis (now an Art Museum) or Ca l'Arañó (multipurpose media space). However, most buildings were iconic new constructions. They accommodated firms such as Indra, RBA Editores, Mediapro or the University Pompeu Fabra.

Table10-2 Audiovisual Campus land use breakdown

Media Campus	
Economic activities	119,486 m²
Facilities	107,721 m²
Green areas	27,714 m²
Affordable housing	413 units

Fig.10-26 Audiovisual Campus general plan (Ajuntament de Barcelona, 2008)

Fig.10-27 Audiovisual Campus . Completed buildings

3. Parc Central

The park that had been proposed in the Special Plan Diagonal-Poble Nou (see above) was now subject of its own Special Plan to adapt some of the initial prescriptions. One of the most singular industrial complexes of Barcelona, Can Ricart, was part of the area of intervention. It had been listed to ensure its preservation. The historic factory Oliva Artés was also listed and classified as 7@, which means that it should be transformed into a facility for new technologies. The district's waste management plant had been built on this site, the plan aimed to qualify it as part of the urban landscape. The design of the park was commissioned to Jean Nouvel, who had authored the neighbour Agbar Tower. Construction works started in 2006, affecting some 200 families and 100 small businesses[113] that had to be removed.

Table10-3 Parc Central land use breakdown

Parc Central	
Economic activities	181,133 m²
Facilities	25,266 m²
Green areas	11,048 m²
Affordable housing	201 units

Fig.10-28 Aereal view and delimitation of Parc Central Special Plan (22@bcn, 2012)

Fig.10-29 Model of the planning proposal with Can Ricart (photo: Generalitat de Catalunya)

4. Pujades-Llull (east side)

The plan proposes the basic conditions to provide a coherent elevation to the streets Llull and Pujades. The axis formed by the three blocks connects the local parks of Poblenou and Diagonal Mar. The urban layout foresees a setback in the south frontage to allow broader vegetated sidewalks.

Table10-4 Pujades-Llull (east side) land use breakdown

Pujades Llull East	
Economic activities	121,594 m²
Facilities	55,902 m²
Green areas	15,746 m²
Affordable housing	277 units

113 Blanchar, 2003

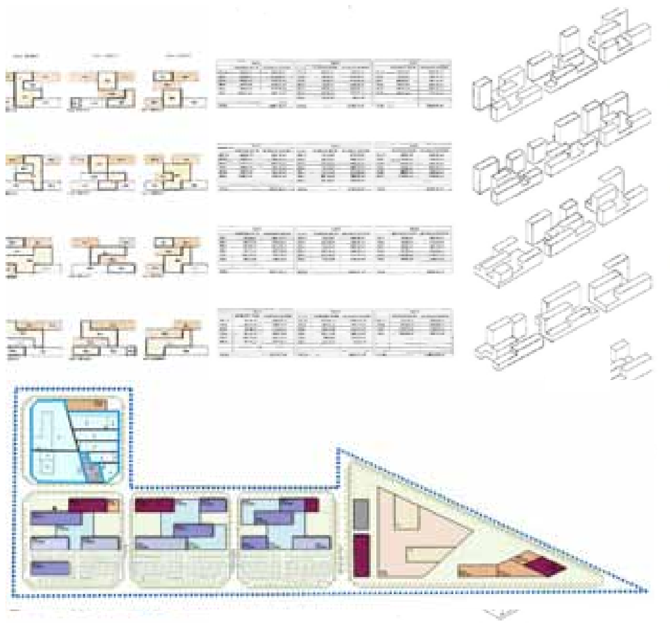


Fig.10-30 Special Plan Pujades-Llull East (Source: 22@bcn, 2001)

5. Pujades-Llull (west side)

It covers 17 blocks in three horizontal bands, between these two streets. It must resolve the connection between the historic fabric of Poblenou, which is outside the 22@ plan, and the Eixample. The plan proposed the specialization of the streets, the concentration of public facilities in strategic axes and the resolution of specific urban situations[114]. In order to achieve a greater level of detail, 12 subsectors were delimited to be individually designed

Table10-5 Pujades-Llull (west side) land use breakdown

Pujades Llull West	
Economic activities	236,662 m²
Facilities	26,295 m²
Green areas	10,725 m²
Affordable housing	263 units

Fig.10-31 Subsector 2 of Pujades-Llull Special Plan, west side (Ajuntament de Barcelona, 2008)

114 22@bcn, 2004

6. Pere IV-Peru

This sector includes six blocks to the north-eastern corner of the 22@ district. The special plan divided each block into a sub-sector, which could be developed independently by private initiave.

Table10-6 Pere IV-Peru

Peru-Pere IV	
Economic activities	138,906 m²
Facilities	19,176 m²
Green areas	3,583 m²
Affordable housing	154 units

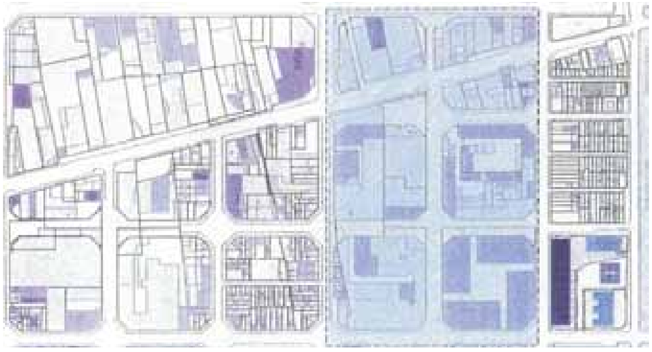


Fig.10-32 Special Plan Pere IV- Perú (Source: 22@bcn, 2003)

It was expected that these six plans of public initiative would provide consistency and legibility to the 22@ operation. The rest of the area would be developed by private agents, without predetermined zones or sectors. Special plans could be initiated by landowners with over 60% of the land within a minimum unit of intervention, which could be a:

- A block
- Half block (with passage)
- Plan on plot over 2,000m²
- Consolidated Industrial building
- Consolidated housing frontage

10.3.2.3.2. Development

The 2012 annual report of the 22@bcn Corporation stated a great advance in renovation works, which had affected up to 70% of Poblenou's industrial areas. 141 development plans were passed, 81 of which had been started by private initiative. It means that over 3 million square meters have become available for offices, housing, facilities and technical services. It was estimated that over 4,000 new companies had settle at 22@ since 2000, creating some 50,000 jobs. It is expected that further 10,000 to 30,000 new jobs could be

Fig.10-33 The 22@ area in 2012 (photo: 22@bcn, 2012)

created upon completion, which would elevate the Poblenou as the most important economic district of Barcelona (concentrating 15% of the economic activity)[115] . As the urban renewal progressed, the focus of the corporation shifted from physical transformation to the marketing and projection of the area. One of the main tasks was to disseminate the association of the district with innovation and economic opportunity. It is undeniable that the marketing efforts have positioned the experience in international bibliography. The identification of clusters in technological sectors (media, ICT, medical, energy and design) aimed not only to enhance competitiveness and networking but also to attract new investment to strength the modernization of economic activities. Examples such as T-Systems, Yahoo Research Centre, Indra or Schneider SmartCity center illustrate the corporation's targets. The ultimate objective was to use the district as any business incubator, so that "any start-up within the metropolitan area can develop its ideas by using the resources that 22@ supplies". The economic and property crisis that started in 2008 has had an impact. Cuts and austerity measures that affected all levels of public administration had forced the suspension of some projects, as the transformation of Can Ricart[116].

Fig.10-34 A resident of Poblenou staring at her old house. The image was used to raise awareness about the social impact of the 22@ (photo: Jordi Secall, reproduced from AAVV,2005)

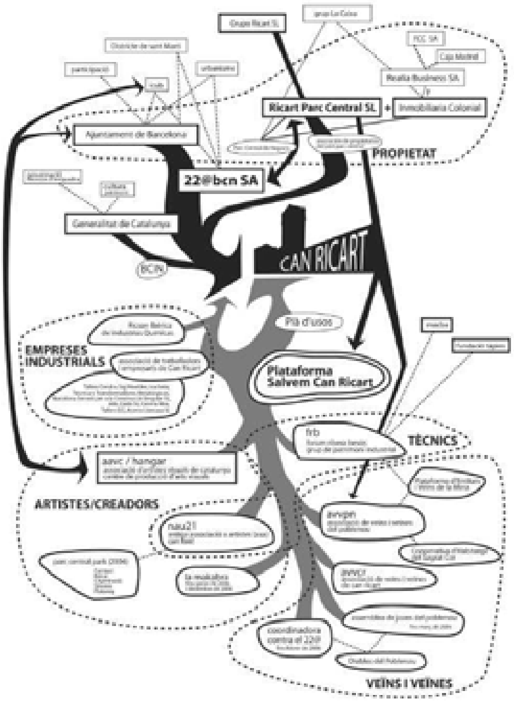
10.3.2.3.3. Social response

The most sensitive part of any urban renewal program lies in the relation with the local community. The accounts of the process had reflected the common dichotomy between the official discourse and the critical opposition. The former reports about indicators, showing the wealth and employment opportunities generated by urban development, whereas the latter focuses on the social consequences. The impacts of the transformation have been twofold. On the one hand, local residents are affected, either directly (demolition of their dwellings) or indirectly (alienation, gentrification...). On the other hand, business may suffer due to the displacement of loyal clientele, disruptions caused by urbanization works and evictions caused by change of use or increasing rents, among other factors. In the case of Poblenou, there was an heterogeneous social structure with different chronological layers: working class residents and remaining business from the industrial period, an emergent bohemian community that had arrived during the eighties and the high middle class families that occupied the new developments at the seafront during the nineties. The socioeconomic context of the Poblenou before the 22@ could be summarized in the following aspects:

- It was eminently industrial. 25% of the economic activities were still industrial (in Barcelona the ratio was 9%) although highly diverse (transport logistics and distribution sheds, small retail and workshops,

Fig.10-35 Campaigns and demonstrations against the 22@ (source: sitesize,2013)

115 22@bcn, 2012
116 Montaner, 2011



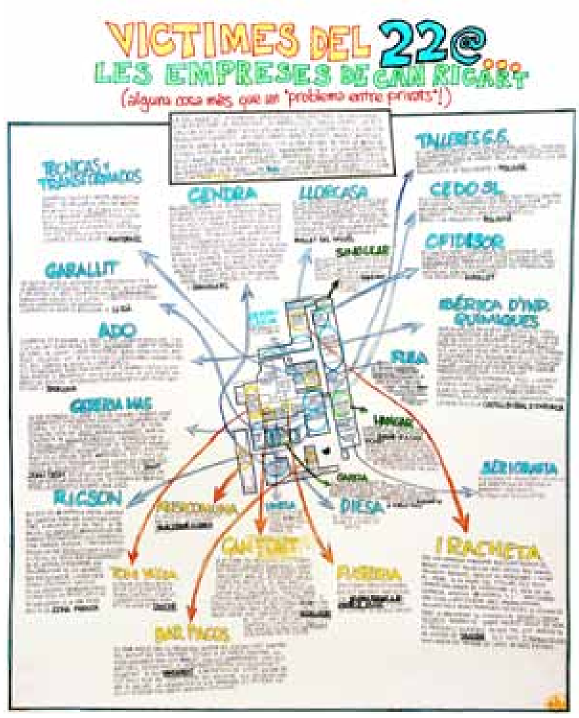


Fig.10-36 Left: “Sociogram, Powergrama” an nfography on who is who at Can Ricart conflict (AAVV, 2005) (Right:Creative cartographies of the alleged victims of the 22@ (ICA, 2006)

catering...)

- Residential density was low and the housing stock was older than Barcelona’s average (90% built before 1953). Moreover, residential use was not permitted by urban regulations before the 2000 Modification of the Metropolitan Plan
- The stock of abandoned structures was increasing. Some of them were of historical interest and others were occupied by artists and bohemians
- The industrial past has, moreover, left a legacy of local associations and a strong sense of identity, which was reinforced by the perception of 22@ as a threat for the neighborhood[117].
- The Barcelonan society was, in general, more cynical about urban renewal than in the eighties. The political shift in favor of private capital, as opposed to social consensus, had been perceived and denounced in journal articles and publications.[118] The community associations heterogeneous and they were supported by intellectual “elites” with a broader perspective.[119]

The points of conflict between local community and 22@ plans could be classified in three main groups[120]:

- **The insufficient consultation** and transparency in decision making, particularly during the elaboration of the Special Plans. The associations considered that the corporation primarily represented the interest of developers and private companies.

- **The building typologies** that were proposed provoked strong reactions. Residents considered that the scale of some of the projects was excessive. They opposed to the construction of tall buildings (up to 24 storeys) because they were strange to the traditional medium rise density of the neighborhood. One of the recurrent claims was the protection of the industrial heritage. The associations were supported, in this case, by intellectuals, such as Horaci Capel, Mercedes Tatjer , J.M. Montaner or Zaida Muxí, who elaborated alternative proposals to put into value historic buildings that were endangered.

-The concerns about the **Social costs** derived from the execution of the plan had various perspectives. Those whose houses or working spaces were listed for demolition were the most directly affected. Many testimonies have been recorded in reports, documentaries and movies[121]. According to estimates made by the local associations, some 1,200 dwellings and 1,000 small businesses may have been evicted due to the 22@ project[122]. The residents felt betrayed and dispossessed as they witnessed how the small companies,

117 New associations were created ad hoc to oppose the 22@ plans (Unió Temporal d’Escribes, 2004 p.265)
118 Delgado, 2007
119 AAVV, 2005
120 Marrero Gillamón, 2003

121 As examples: Sucari, 2011 , Pashiou, Trigo & Peña, 2010
122 As Marrero Gillamón, 2003 points out, these figures differ from those of the council

where they have been working for many years were being replaced by glossy offices, where they can hardly find a job. Moreover, the progressive gentrification was another cause of concern for the local community. The neighbourhood was deliberately put into the market as an investment opportunity and a "cool" place to live. The flip side of 22@ success was a substantial increase of property prices that would force young local generations out of the Poblenou. The anthropologist Manuel Delgado pointed out how on the same day local papers announced, in 2006, two records that had been beaten, one regarding the construction of new office space and, a second one, regarding housing price, which was at its peak. It was, he added, indicative of the kind of city Barcelona was aiming to[123]. The residents could not benefit from the success of redevelopment as trickle-down theory did not work and, moreover, many of them could not access a house or a job in their neighbourhood.

There was a third sector that has been affected by the transformation, which is particular to this case: the artistic community. As it has been mentioned, creative groups had been attracted by cheap rents to establish their workshops. Most of them were independent artists, or recent graduates from the School of Arts, searching for space where to produce, rehearse and perform their activities. Some of them gathered in art centers, occupying old factories such as "La Escocesa", Can Font and the most emblematic one at Can Ricart. Other groups, such as Palo Alto or Hangar, had institutional links. Some of these groups elaborated a series of cartographies where the affected activities were mapped. It was estimated that 18 art centres were lost and 133 expelled between 1994 and 2006 and that other 188 would follow in 2007[124]. The closure of these spaces was preceded by intense opposition campaigns in what has been coined as "creative sprawl", since many of the artists moved to other municipalities[125]. The art community was an asset of Poblenou, rather than a burden. What urban students criticized was the contradiction between the claims of the 22@bcn corporation regarding creative talent and the apparent disregard for a well established, dynamic and renowned colony of artists that existed in the area.

10.4. 1981- 2012 The physical transformation of the Poblenou

After thirty years of regeneration, the transformation of Sant Martì and Poblenou is still ongoing. Over 500 hectares of the former industrial district are included in the area of influence of the different projects that, over the years, aimed to adapt this central location to a new urban model. Although four times smaller than Docklands, its higher density (206 ppha compared to 87ppha in Docklands) places it amongst the largest infill regeneration projects in Europe. This compactness, together with the organizational strength of the urban grid, admits the identification of a coherent urban context, within clear boundaries defined by prime avenues (Meridiana, Gran Vía de les Corts Catalanes and Rambla de Prim) the Citadel Park and the coastline. However, this precinct was neither homogeneous before regeneration nor it is after it. As in Docklands, the different character of some of these areas has been enhanced by the transformation, mainly as a result of the blend between new and old urban structures. In those places where it was possible to combine both, the reactivation of urban life was easier. Such important factors as sense of place and identity were preserved while introducing new spaces to meet the needs of the new urban model. In contrast, those areas where a clean slate approach was applied had divergent results. While the Olympic Village is successfully integrated in the city, the Forum and its surroundings still has a negative connotation and lacks identity.

Fig.10-37 Axonometric view of Poblenou around 1981. Red: residential. Violet: Industry and Tertirary. Blue: Facilities

Fig.10-38 Axonometric view of Poblenou around 1981. Red: residential. Violet: Industry and Tertirary. Blue: Facilities

Notwithstanding the chronology of interventions show in figure 10-20, the district could now be grouped in five different zones with shared attributes after the regeneration:

- The seafront strip, from the Olympic Village to Poblenou Seafront. This area has been transformed on its majority. The old industrial facilities have been demolished and replaced by housing blocks of various typologies, while tertiary uses have been concentrated at the Olympic Port.

123 Delgado, 2007
124 Bosco, 2007
125 Tironi, 2008

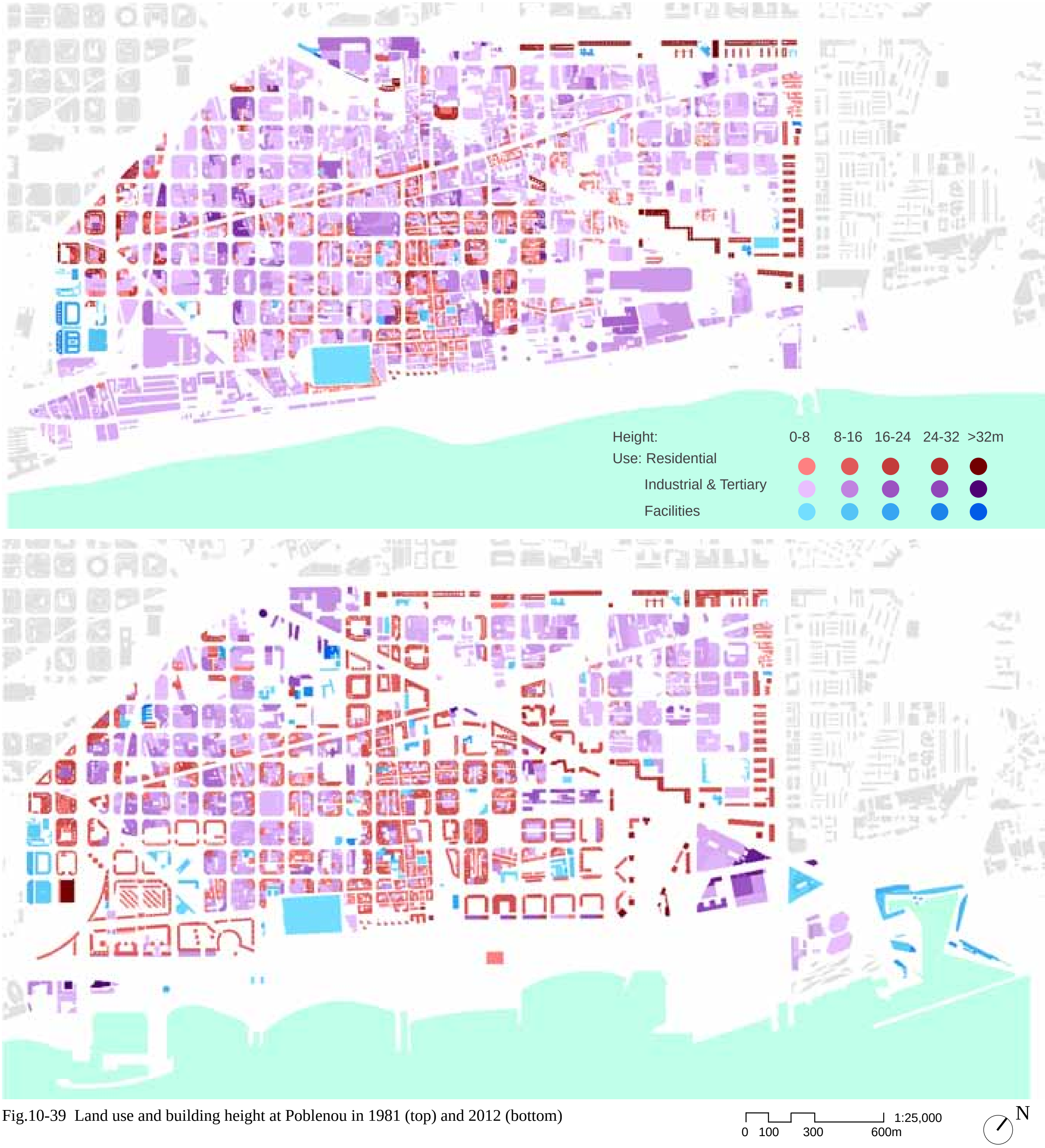


Fig.10-39 Land use and building height at Poblenou in 1981 (top) and 2012 (bottom)

The proximity to the sea and the urban centre has made it one of the most demanded, and therefore expensive, zones in Barcelona (after the Eixample, Pedralbes, Gracia or Sarriá). Architecture and urban design have played major role as it can be noticed in the implementation of bespoke solutions, the diverse reinterpretation of Cerdà's grid and the humanization of infrastructure. The industrial legacy is limited to the use of brick and a concealed water tank at Plaça Ramón Calsina. The new identity is rather constructed on the Mediterranean character, with a sequence of streets, arcades and squares designed for the pedestrian. Only the area around the port presents, as mentioned in previous paragraphs, a deviation

Fig.10-40 Demolished buildings during the period 1981-2012 (in colours)

Fig.10-41 New constructions during the period 1981-2012 (in colours)

0 100 300 600m 1:25,000 N

towards standard commercial development.

- The Forum of Cultures is the joint between Poblenou and a varied urban mosaic, composed of large urban utilities, the Besòs estuary and La Mina neighbourhood. It meant a change of scale, neglecting the unity of the urban block and the street in favour of tower blocks, deep malls and massive concourses designed for the special event. Extenuating circumstances are that the area should incorporate facilities that are normally externalized, such as water treatment plant and an incinerator, which, together with a photovoltaic screen, are alleged to provide about 40% of the resources


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Fig.10-42 Overlapping of current (in colours) versus previous (grey lines) state

for the surrounding district[126]. However, this change of scale was transferred to Diagonal Mar residential development, an introverted scheme, deliberately designed as defensive and enclosed enclave.

- The old Poblenou is clustered around the Rambla, which connects the seafront with Pere IV street. It preserved the existing fabric and benefitted from the existence of a sound social structure. It remains as the core of the neighbourhood, the area where activity concentrates, during daytime but even more after working hours. For these reasons it has been kept aside from holistic development plans and only small reform interventions have been carried out.

- The southern 22@ plan (pink in figure 10-20), in combination with the upper section of Diagonal Avenue can be distinguished as representative of the most recent regeneration approach. It is not only the location of the neo-tertiary activities (digital, research, innovation...) but it also aims to express it unambiguously by the symbolic expression of its architecture and urban design. Although the 22@ plan prescribed piecemeal interventions on strategic spots, the transformation concentrated around the south part of Diagonal during the initial stages. Consequently the regeneration of this area has advanced at a faster pace, replacing the old sheds by a collection of singular buildings. As the iconic value favoured the marketability of office space, buildings compete to project their presence in the city. Agbar Tower, RBA building or the Media TIC are only some examples. In contrast, less attention was paid to public space, which is only considered as a mere recipient of cables, pipes and other hyper-sophisticated infrastructures.

- The northern part of the 22@ plan (pink in figure 10-20), is behind in the regeneration process. The main transformations were carried out under the Diagonal Poblenou plan but the presence of low quality industries and underused spaces is still strong. Only two blocks have been refurbished at the moment.

10.4.1. Densification and Intensification

As in the case of Docklands, the selection of Pobenou as case study was based on the densification process and the mitigation of urban sprawl exemplified by infill interventions. Overall density values after and before the process can be checked in figure 10-47. The FSI has been increased an 80% while population rise was about 60%. However, the highest increase was for the number of jobs, which have reached almost 200%.

Spatial network analysis was undertaken to visualize further effects of the transformation on the built fabric. The Urban Network Analysis tool was used to accomplish this task[127]. It is a GIS based application that computes five types of network centrality measures on spatial networks: Reach,

126 Acebillo, 2012

127 cityform.mit.edu/positions.html [last accessed 27.11.2013]

Fig.10-43 Poblenou 1981. Betweenness Radius:1,000m Building weight: Volume

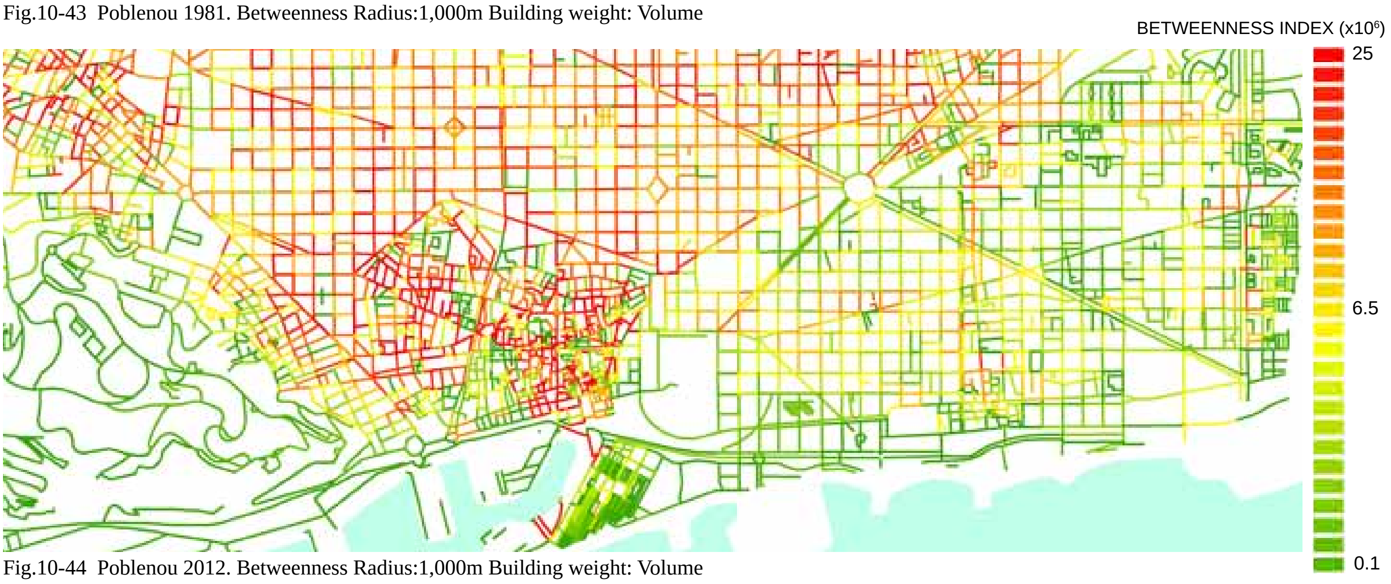

Fig.10-44 Poblenou 2012. Betweenness Radius:1,000m Building weight: Volume

Fig.10-45 Barcelona 2012. Search Radius:1,000m Building weight: Number of units (tertiary)

1:200,000

0 1 2 4Km

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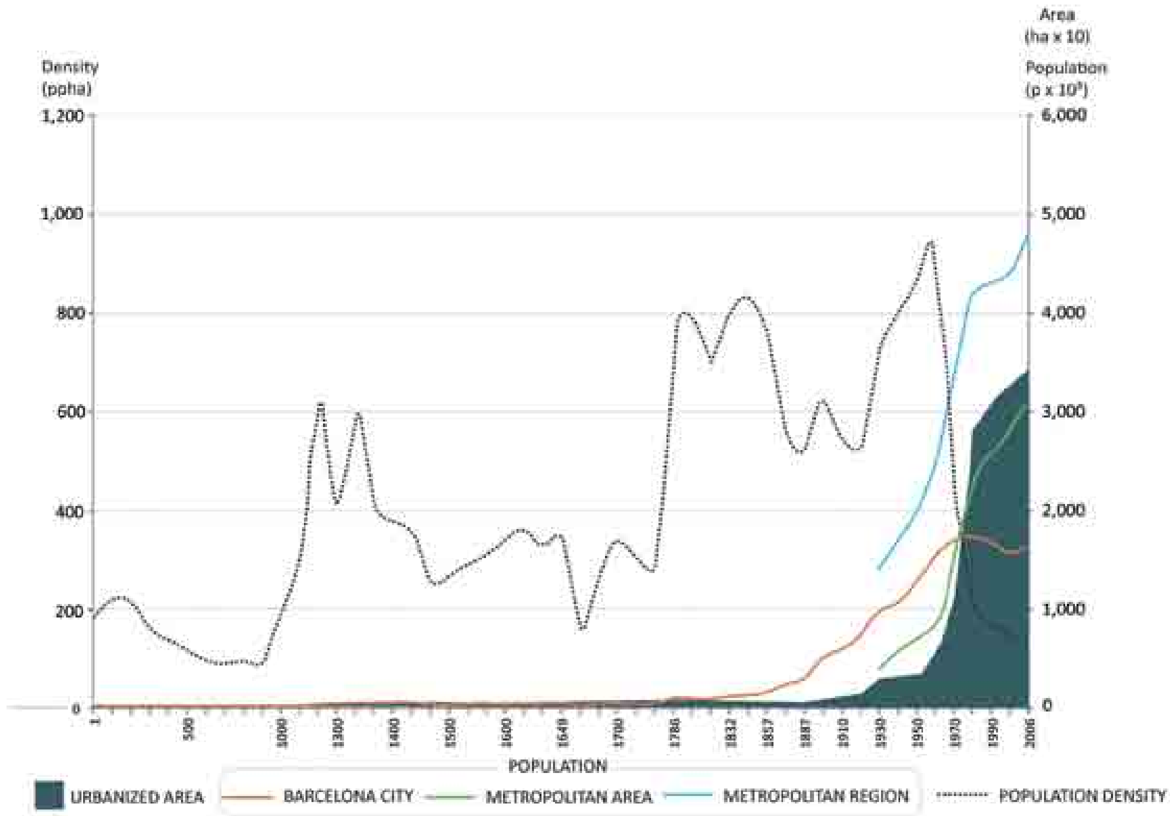

Fig.10-46 Historic evolution of Density, Population and Urbanized Area in Central and Metropolitan Area of Barcelona

Gravity Index, Betweenness, Closeness, and Straightness[128]. The main advantage of this tool respect to similar instruments lies in its accountability for buildings as connected to the network, which allows to combine notions of density, choice centrality or accessibility. In Docklands, the measure “Reach” was used to compare the scenarios in 1981 and 2012. In this case, a different metric, “Betweenness” will be applied since the important transformations on the road network may be better illustrated using this parameter. The betweennes-centrality estimates de number of times that each element in the network lies on shortest paths between pairs of other reachable buildings in the system, within a given radius If may be used to capture the potential passers-by on each street or building in the network[129]. and gives an idea of their topological connectivity and interaction opportunities. The tool takes all buildings and records all possible origins and destinations; it then calculates the shortest path to connect each origin and destination point and assigns an increment to each section of the network for each route crossing that section. These values can be weighted by other parameters such the built density, population or the number of establishments that lay in each building. In this case, built density and a 1,000 meters radius were used as input parameters.

The results from the analysis shows the improvement in accessibility after the eastern section of the Diagonal Avenue was open. In 1981, flows were concentrated in Pere IV and the Rambla of Poblenou as many other routes were truncated by sheds or were simply not urbanized. As alternative paths were made available, the flows in 2012 are a bit less concentrated. Points that formerly lacked proper access acquired a new connectivity. However, the affluence of passers-by in Poblenou remains substantially lower than at the Eixample and the Gothic quarter.

A second analysis was carried out to visualize the measure of “Reach” parameter after the regeneration (fig. 10-45). The same analysis had been done in Docklands and, as in that case, a weighting factor was applied to account for the number of different premises that can be reached within a 1,000 m radius. The unit of aggregation was the urban block and only non domestic establishments were considered. High values in the reach index indicate a greater diversity and interaction opportunities, which is typically associated as an intrinsic value of urban life. It can be noticed how density and fragmentation are combined to give higher values in those places with high density and smaller units (offices, shops...). Poblenou shows lower values than the Gothic Quarter and the Eixample, which are denser and more populated.

Finally, the change of trend exemplified by the redevelopment of Poblenou is illustrated at regional scale in figure 10-46. Although population increase in the periphery

128 Sevtsuk & Mekonnen, 2012
129 Ibid

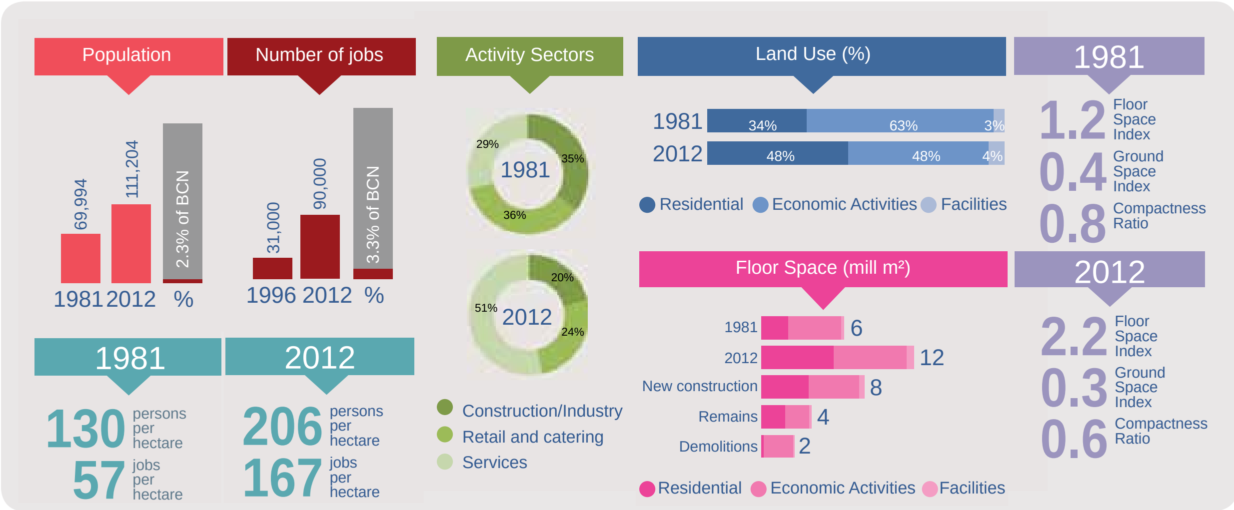

Fig.10-47 Summary statistic of Poblenou transformation

is still offsetting the feeble rise at the city centre, it represents, at least, a reversal from the continuous decay that stated in the 1970s.

10.5. Conclusions

The end of dictatorship was, in many senses, a release for Barcelona. The early democracy was a period characterized by optimism and dynamism, but also a time of challenges in a difficult economic situation. Demographic flows indicated a progressive migration from the city center to the suburbs, caused by the degradation, overcrowding and specialization of former residential areas, such as the Eixample or the Gothic quarter. At the same time, shanty towns were scattered around industrial districts, lacking the most basic hygienic and health conditions. It strengthens the negative perception of the city by the emergent middle class, who fled to low dense suburbs beyond Collserola. The council, led by its Urban Department, set an agenda to counteract that centrifugal trend. They aimed to qualify the city centre. An ambitious programme of interventions on public spaces would amend an historic deficit. Over 150 squares and streets were refurbished in order to improve the environmental quality of dense neighbourhoods, thus creating an appeal for residents to stay. A second plan identified strategic points in the city that would be redeveloped in order to create “New Centrality Areas” and, consequently, reduce the pressure of tertiary uses on the Eixample. The plan received a huge impulse when, in 1986, Barcelona was nominated to organize the 1992 Olympic Games. It established a deadline and it opened new channels to finance the works. The urban strategy for the games was based on the previous plan and venues were distributed over four of the new centralities. Although Barcelona was one of the densest capitals in Europe, intense sprawl was taking place. The densification of Poblenou, the underdeveloped industrial borough, was a measure of urban containment. Therefore, instead of locating the Olympic Village somewhere in the suburbs it was decided that it would stay in one of the most central locations. The Olympic Village can be understood as the first experiment to revitalize the centre and to counteract the migratory patterns in Barcelona. The following experiences would still focus on the margins of Poblenou, with successive large scale interventions at the Seafront, Diagonal, Diagonal Mar and Forum. However, the regeneration approach had changed. Private capital was becoming more decisive and influential. The experience from the Games had been positive, in general terms, and the council aimed to take advantage of the image of the city to attract massive investment to fund further urban projects. The agenda of the Centrality Areas was followed but the programme shifted to satisfy commercial interests. The rather general social consensus was replaced by local opposition as the scale and degree of intervention increased. The physical results were heavily criticized as being banal and lacking any sense of place. Some of these issues were addressed when a new strategy was devised for the regeneration of the internal blocks of Poblenou. Inspired by successful precedents in Silicon Valley or Bangalore, a plan to create a technological district, namely 22@, was elaborated. The iconic image for this new techno-urb was Jean Nouvel’s pixelized gherkin-style tower, which was not part of the plan but it was a convenient landmark for the marketing of the place. Unlike the Olympic Village, the 22@ plan did not remove all pre-existing buildings and preserved part of its industrial heritage. The juxtaposition of shiny new office buildings with old housing and historic factories results awkwardly forced but it is, arguably, more truthful than the pretended simulation of organic growth of the Olympic Village. As in other regeneration examples, the promoters based the success of the strategy on economic indicators such as employment figures or foreign investment, whereas opposing forces argued on the quality and the negative consequences inflicted upon local population and existing socio-economic structure.

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CHAPTER 11

COMPARATIVE ANALYSIS AND PERFORMANCE ASSESSMENT

In previous chapters, the chronicle of transformations on the central areas of London and Barcelona illustrated the multiple factors and colliding interests that are involved in actual densification processes. The debate about performance and urban form tend to digress to a high level of abstraction, especially when drawing assessments based on rhetoric inference. On the other hand, if the assessment criteria are restricted to quantifiable parameters (e.g. environmental or economic indicators) social effects may be disregarded and sidelined. The compact city discussion has been fundamentally based on assumptions that, although plausible, have been seldom supported with empirical evidences, other than data from transport studies or other partial performance indicator[1]. Conversely, cases of urban renewal have been typically addressed from social[2], planning[3] or urban design[4] perspectives. Depending on the approach, the arguments may vary from the telling vindication of density as the ultimate solution to reduce carbon emissions to its strong opposition as the origin of social distress. The use of real examples aims to provide an holistic reference on the magnitudes and consequences of urban transformations, in terms of quantitative performance and social impacts alike. Only then, it will be possible to draw a critical evaluation, based on objective analysis and rational judgment. Essentially, the appraisal, aims to answer the following questions:

- How significant are the potential energy savings derived from urban compaction?
- What are the collateral effects of further densification in consolidated urban areas?
- Do potential benefits outweigh these potential side effects?
- Is there a softer alternative that can deliver similar benefits?

On the other hand, the understanding of ongoing urban transformations requires a deep knowledge on the intrinsic nature of cities. This is, how they have flourished, matured, evolved and how and why some parts decayed and became obsolete. From this knowledge future scenarios can be forecasted and evaluated. Generally speaking, the history of London and Barcelona do not differ greatly from the chronicle of other European capitals. An initial and steady urban formation, built over centuries, was accelerated by the advent of the industrial economy, which induced a shift of scale. Large industries attracted massive flows of population. Cities had to absorb the new residents either by densification, expansion, or a combination of both. The different geographic and social structure determined, in each case, divergent results and a broad catalogue of urban forms. Recent studies, which addressed the morphological transformations of those cities, have been discussed in previous chapters[5]. They typified the prevailing forms as hybrid systems composed of multiple urban entities, still dominated by the original city, but with various metropolitan structures. They could be described as polycentric metropolis with a different degree of hierarchical association: while some of them have retained a strong core, surrounded by radial satellites, others are formed by an homogenous constellation of complementary centers.

11.1 Form and Performance in London and Barcelona

One of the main targets in this research was to decipher the connections between urban form and specific performance variables, with a special attention on energy patterns. Case studies in London and Barcelona were selected to test on real grounds otherwise abstract hypothesis. Both cities had experienced a process of decentralization of residence and economic activities, started in the seventies, and followed by a number of countermeasures to reactivate the interest for the inner city. However, the existing spatial structure differed greatly, as London exemplifies the vast low dense and extensive metropolis whereas Barcelona is a paradigm of compactness and urban containment. The transformations undertaken in London Docklands enabled the establishment of more than 140 thousand new residents and nearly 200 thousand jobs in a central location that had been underused for more than a decade (fig.11-1). Similarly, the urban projects at Barcelona's Poblenou attracted around 40 thousand residents and 60 thousand job positions, with predictions of 100 thousand new jobs in the near future. If , instead of regeneration, the previous sprawling trends were continued, these new population would have been derived to some suburban enclaves, where housing and tertiary space could be provided at a lower cost. In contrast, policies of

1 As example: Cervero,& Kockelman, 1997
2 As example:Foster, 1999, Brownill, 1990
3 As example:Couch et al, 2003
4 As example: Ajuntament de Barcelona, 2008a

5 Font et al, 2007 Hall&Pain, 2006 Oswalt &Rieniets, 2006

Fig.11-1 Summary statistics of the transformations in Docklands and Barcelona

urban containment were implemented. Either purposely or as a consequence of other intentions, the density of large central districts was notably increased. In Docklands, which was sparsely populated and industries had been scrapped, residential density increased by a factor of five (from 19 to 87 persons per hectare) and employment density by a factor of 8 (from 13 to 106 jobs per hectare). Although Poblenou could be considered a dense district when renewal started (130 ppha), an increment of 60% in population has been so far introduced, whereas the number of jobs in the area has almost tripled.

Alongside physical regeneration, the local economy embraced a new model, abandoning the traditional manufacture and transformation industries to decidedly engage service activities (or using Acebillo's term neo-tertiary[6]), which passed to represent over 50% of job positions in 2012 (fig. 11-1). Financial services in Docklands and research and innovation in Barcelona concentrated most

6 Acebillo et al, 2012

of the new employment, which improved the perspective of the labour market in the respective districts. Despite the strict dependence between unemployment figures and the economic context, it can be noticed that the relative performance in both cases has improved. In the 1980s these industrial districts presented much higher rates of unemployment than the rest of the city (almost 10 points higher in Docklands than for London as a whole and close to 6 in the case of Poblenou respect to Barcelona). The gap has become much smaller for the residents of Poblenou (2.4 in 2012) and it has been reversed at Docklands (0.4 % less unemployment than in London), which may indicate, after all, that opportunities arouse from the urban transformations of these areas.

It can be argued that native residents were forced to leave rather than taking advantage of "trickle down" opportunities. This may have been true in some cases, and it was extensively discussed in previous chapters, but construction figures suggest that, overall, most of the original settlements were respected. Approximately ten percent of the pre-existent residential floor area within the two study areas was demolished during the last 30 years, which is a low ratio even for zones that have not been subject of urban renewal programmes. Most of the demolition works affected industrial facilities, of which only 50% of the original floor space survived after the process. Densification was, therefore, largely based on the transformation of industrial land and vacant plots. As the new economic activities required smaller spaces (offices and desks instead of sheds or shipyards) part of the formerly industrial land was designated for residential use, thus balancing domestic and non domestic uses. The overall Floor Space Index (FSI) was doubled in the case of Docklands (0.81 to 2.01m²/m²) and substantially increased at Poblenou (1.18 to 2.18m²/m²). However, the occupation of land was reduced in the latter (from 0.44 to 0.36m²/m²) as regeneration also involved the disposal of constructions that were occupying the public space. It could be said that Docklands took a clean slate approach, enabled by the relocation of the port and extensive industries whereas in Poblenou there was a combination of medium sized plots of land, which were made available over time, and piecemeal interventions in interstitial areas and leftovers. Both resulted in denser environments with enhanced connectivity with the core city and a varied offer of activities.

It is undeniable that, under current standards and compared to their state before regeneration, the urban quality in the study areas has been greatly improved. It is also clear that these transformations inflicted a considerable strain on local workers and residents. These factors have been illustrated by the detailed account of the events in Docklands and Poblenou, which portrayed a comprehensive picture of the consequences of urban compaction, beyond theoretical lucubration and abstract determinism. However, it is the objective of this thesis to provide further insights to existing theories on urban form and performance. This was the main reason why London and Barcelona were selected, as they represent opposite spatial structures, the former being the example of scattered city and the latter the paradigm of compactness. When both cities engaged the renovation of inner districts they were applying, in practice, some of the postulates of contemporary sustainable urbanism, which advocates for containment and anti-sprawl policies. Ideally, they would provide some evidences to support such theories. However, despite the fact that the case studies are among the largest urban interventions in Europe in the last decades, their relative weight in the overall urban performance may be little as they account for less than 4% of the population and a similar proportion of the urbanized area. To get an idea, if, say, the energy demand per capita on these districts was halved as a result of improved performance (for instance due to more efficient buildings and less need for travel) the overall reduction in the city's energy bill would be as little as 2%, a value that can be easily concealed by feedbacks effects, external factors or even by marginal errors in data collection. Essentially, the case studies advanced possible consequences of densification processes and patterns of performance that should be widely implemented if they were to have a significant impact at city level.

Subsequent research has combined empirical observations with theoretical speculation to explore the consequences from urban policies leading to further compactness as opposed to the continuation and enhancement of previous decentralizing trends. Energy performance per capita was the key variable to compare different scenarios. Personal travel and domestic heating load were then the specific factors whose variations would be estimated in relation with alternative spatial arrangements[7]. All the analyses consisted on two stages:

- The first stage was based on thorough observations of existing patterns, based on contrasted data and the analysis of energy flows in the current urban structure.
- In the second analytic stage, exploratory urban models were elaborated based on the outcomes from the previous phase. These models aimed to depict hypothetical scenarios for the future evolution of London and Barcelona, based on their current structure and assuming alternative degrees of compaction and sprawl for each scenario. Finally, an estimate for energy demand per capita was calculated for each scenario, using the tools and methods developed in previous chapters.

7 These two factors account for about 27% of the total energy in UK and are influenced by urban form. Other factors that to consider can be found in chapter 4, fig 4-24. The detailed calculation of all them goes beyond the scope of this thesis.

L1 FSI: 6.37 GSI: 0.60 Comp:0.47
Heating: 62 Lighting: 66 Cooling:00

L2 FSI: 1.34 GSI: 0.29 Comp:0.82
Heating: 69 Lighting: 39 Cooling:01

L3 FSI: 2.55 GSI: 0.39 Comp:0.64
Heating: 62 Lighting: 46 Cooling:02

L4 FSI: 4.57 GSI: 0.61 Comp:0.55
Heating: 64 Lighting: 64 Cooling:00

L5 FSI: 3.57 GSI: 0.53 Comp:0.54
Heating: 60 Lighting: 52 Cooling:01

L6 FSI: 1.23 GSI: 0.26 Comp:0.84
Heating: 70 Lighting: 38 Cooling:01

L7 FSI: 3.93 GSI: 0.51 Comp:0.70
Heating: 73 Lighting: 61 Cooling:00

L8 FSI: 2.86 GSI: 0.60 Comp:0.66
Heating: 66 Lighting: 51 Cooling:01

L9 FSI: 2.31GSI: 0.46 Comp:0.73
Heating: 67 Lighting: 45 Cooling:01

L10 FSI: 1.05 GSI: 0.24 Comp:1.01
Heating: 78 Lighting: 33 Cooling:01

L11 FSI: 0.81 GSI: 0.29 Comp:0.96
Heating: 74 Lighting: 38 Cooling:00

L12 FSI: 0.83 GSI: 0.34 Comp:0.96
Heating: 73 Lighting: 40 Cooling:00

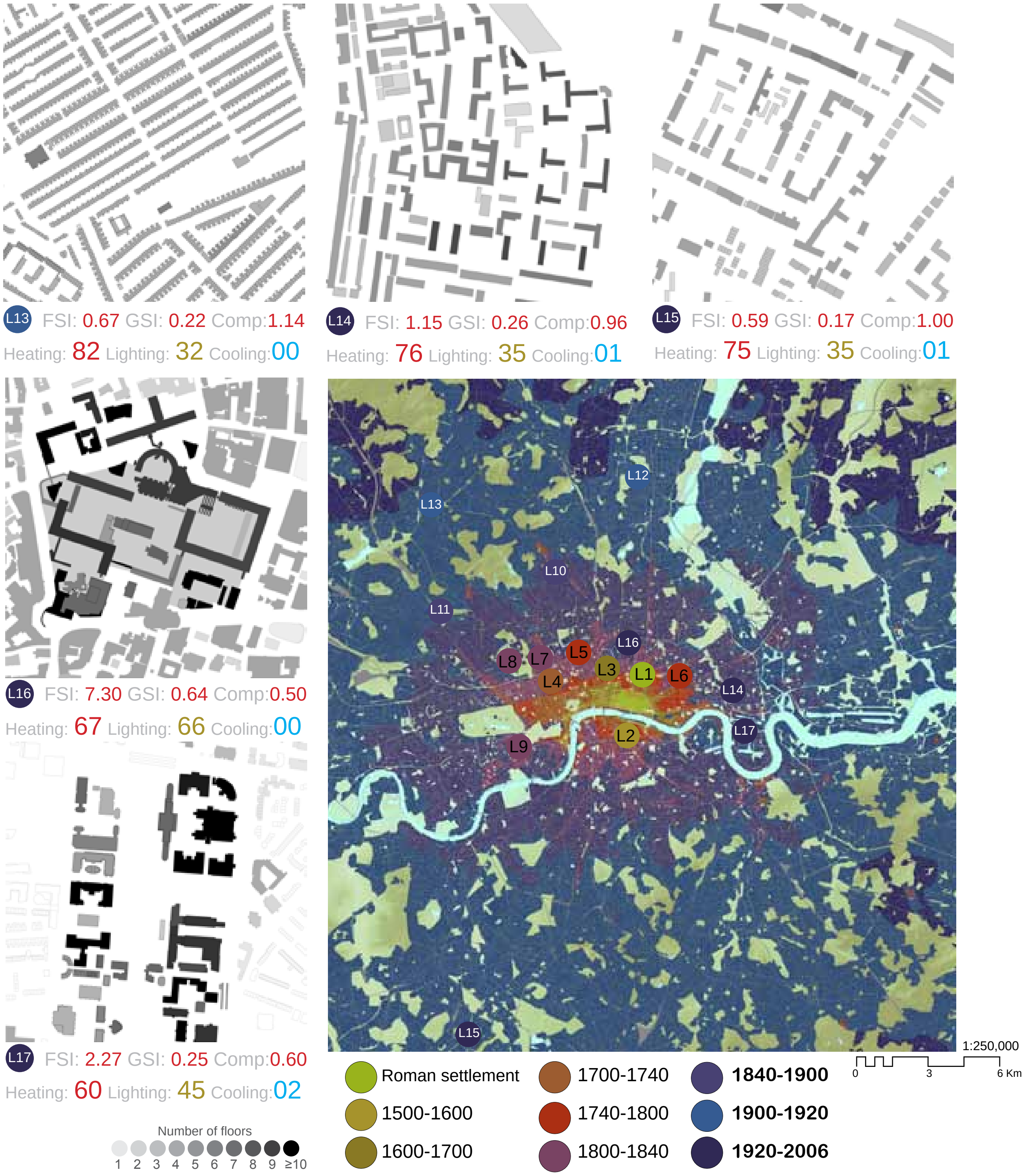


Fig.11-2 London: Forms of urban growth and energy performance

B1 FSI: 3.11 GSI: 0.81 Comp:0.42
Heating: 07 Lighting: 58 Cooling:10

B2 FSI: 2.74 GSI: 0.85 Comp:0.44
Heating: 07 Lighting: 59 Cooling:10

B3 FSI: 2.54 GSI: 0.83 Comp:0.45
Heating: 07 Lighting: 59 Cooling:10

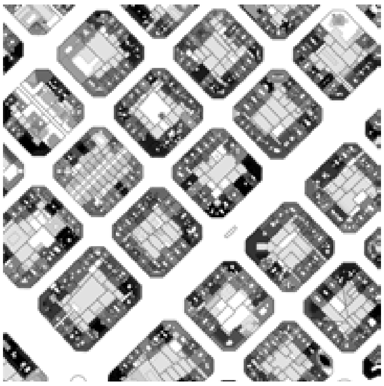
B4 FSI: 3.01 GSI: 0.79 Comp:0.48
Heating: 08 Lighting: 56 Cooling:10

B5 FSI: 2.69 GSI: 0.61 Comp:0.55
Heating: 10 Lighting: 50 Cooling:11

B6 FSI: 2.54 GSI: 0.79 Comp:0.52
Heating: 09 Lighting: 55 Cooling:10

B7 FSI: 2.29 GSI: 0.79 Comp:0.54
Heating: 09 Lighting: 56 Cooling:10

B8 FSI: 2.28 GSI: 0.58 Comp:1.07
Heating: 18 Lighting: 52 Cooling:09



B9 FSI: 2.83 GSI: 0.51 Comp:0.99
Heating: 17 Lighting: 62 Cooling:09

B10 FSI: 1.73 GSI: 0.22 Comp:0.89
Heating: 16 Lighting: 34 Cooling:10

B11 FSI: 1.15 GSI: 0.23 Comp:0.98
Heating: 16 Lighting: 31 Cooling:10

B12 FSI: 0.29 GSI: 0.15 Comp:1.33
Heating: 20 Lighting: 29 Cooling:10

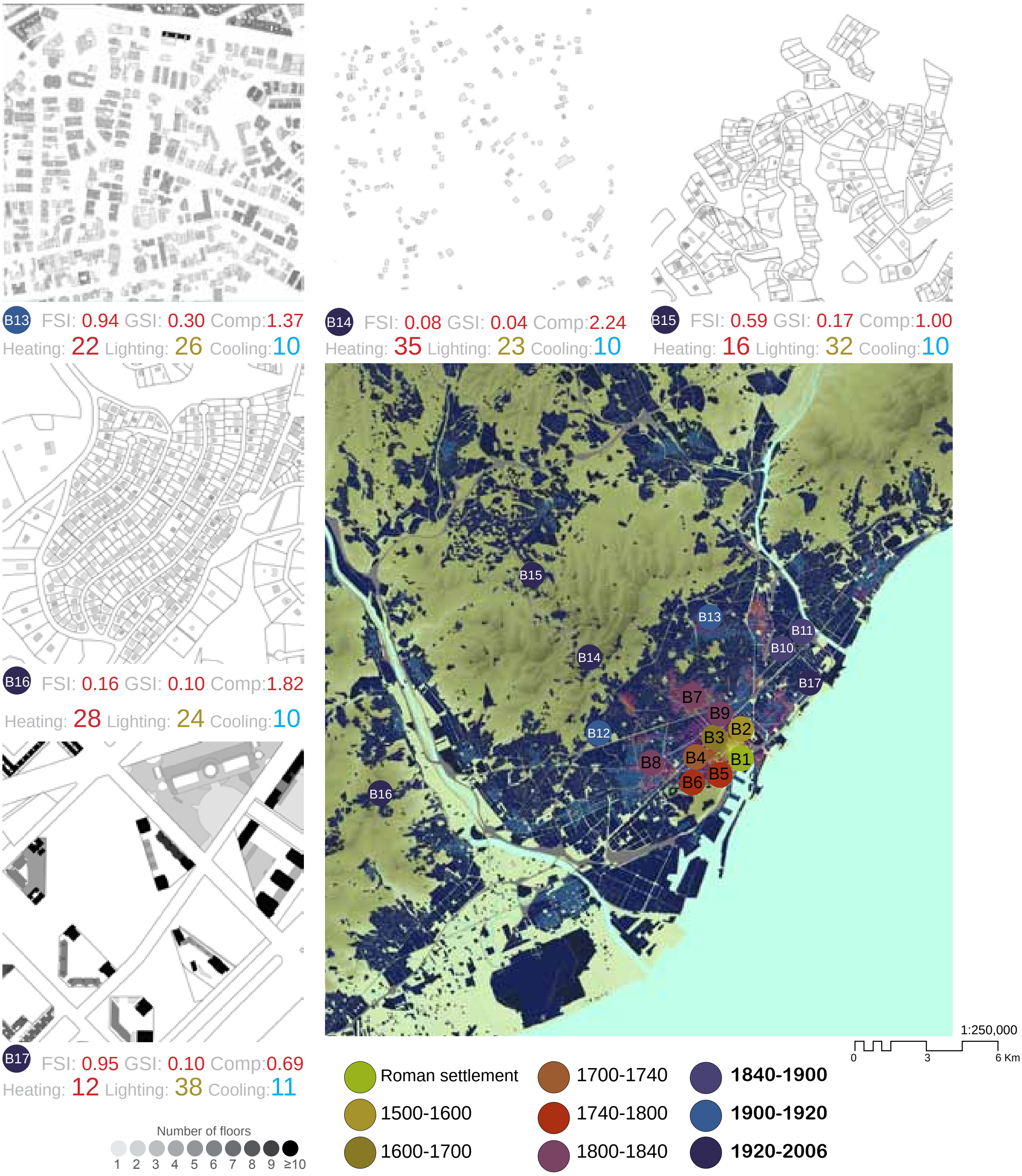


Fig.11-3 Barcelona: Forms of urban growth and energy performance

11.2 Urban fabric and domestic heat load in London and Barcelona

Domestic space heating represents about 40% of the total energy use in residential buildings in the Spanish Mediterranean zone[8] and above 50% in the UK[9]. Since domestic sector is one of the largest single consumers, reaching up to 40% of the total energy in UK[10] and around 20% in Spain, the contribution of space heating to the overall energy intake in cities and nations is most significant. For this reason, heating load was selected as key indicator of energy urban performance in this study, as it offers the greatest insight for a single variable. Notwithstanding the relative pertinence of other end-uses, such as lighting, cooling or hot water and other building types, such as offices, schools or hospitals, they were not addressed at the same level for the sake of legibility and to avoid excessive repetition. Although they were estimated in the analysis of the existing urban typologies, they were not considered for the assessment of scenarios. It can be assumed that, once the heating load patterns were known, others could be calculated using the same methodology or they could be derived from the knowledge gained on heating performance[11].

The building energy analysis started by looking into the performance of the existing urban fabric. Prevailing typologies were identified in London and Barcelona, following the studies of the forms of urban growth associated with the evolution described in chapters 7 and 9. Each typology corresponds to an specific historical period and they tend to be clustered in concentric rings. In this way, the central tissue is typically denser and crowded as result of its medieval origins and the peripheral zones tend to be formed by open and low rise developments. Energy load was calculated for every urban typology, using the Urban Energy Index model with the climate of London and Barcelona accordingly. In order to introduce the urban types into the UEI spreadsheet, their characteristic parameters, Floor Space Index (FSI), Ground Space Index (GSI) and Compactness (Comp) were calculated and written down. Values for heating, lighting and cooling were obtained but, as mentioned before, only the heat load was carried forward for subsequent analysis.

The results from the typological assessment are illustrated in figures 11-2 and 11-3. Heating load presents variations up to 30% in London and 80% in Barcelona for the different types. In absolute terms, heating consumption per square meter is about three times higher in London, due to its colder climate. Therefore a variation of 30% is, at least as significant as the largest fluctuation in Barcelona. Dense and compact areas, which have lesser exposure, offer the lower values in

8 IDAE, 2011

9 Utley & Shorrock, 2008

10 See figure 4-24

11 It must be also pointed out that the influence that urban form has on heating is considered stronger than for other uses

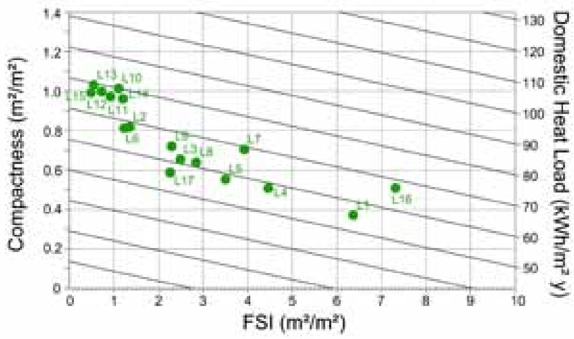


Fig.11-4 UEI diagram for domestic heat load for London with urban typologies

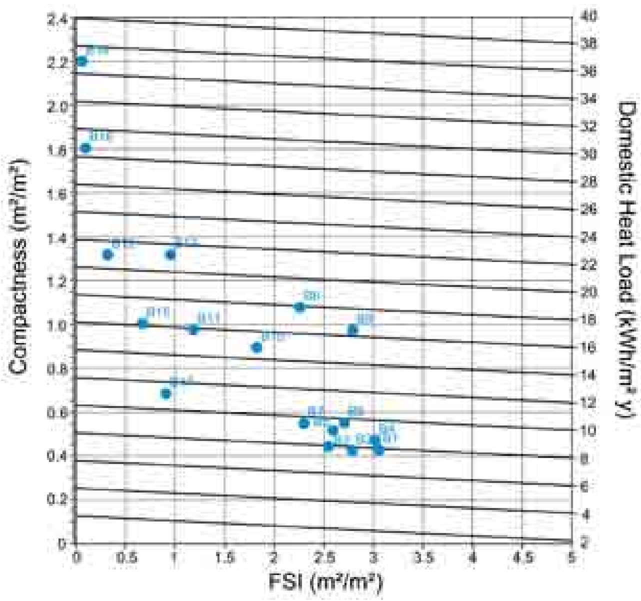


Fig.11-5 UEI diagram for domestic heat load for Barcelona with urban typologies

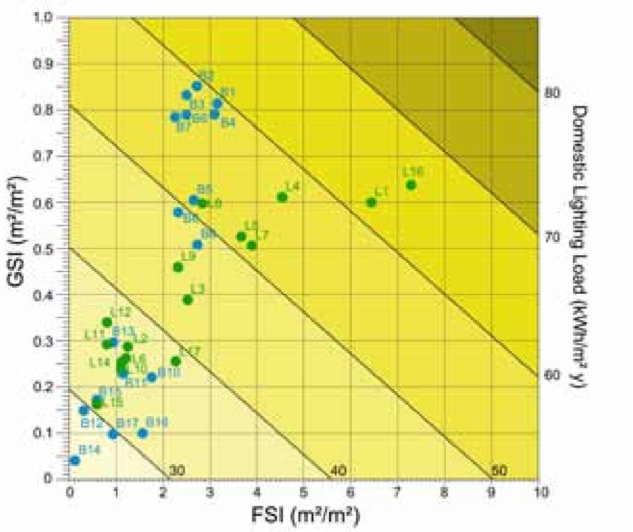


Fig.11-6 UEI diagram for domestic lighting for London and Barcelona with urban typologies

both cities. In contrast, terraced and detached housing are confirmed as the poorer performers. It is important to remind that the UEI model assumes pre-established values for building elements, such as insulation, windows or occupancy patters, which are the same in all simulations. The model only accounts for urban variables[12].

Scatter plots relating spatial variables to heating and lighting loads were drawn up following the methodology explained in chapter 6 (figs 11-4 to 11-6). A total of seventeen observations were selected in each city. The samples were meant to cover the main urban typologies that can be found in the case studies, so that they provided an expected range of values when carrying out city-wide analysis. The diagrams proved a high predictive capacity as the standard error was around 3% for heating and 6% for lighting. A number of insights were extracted from the analysis of the graphs:

- Domestic heat load is best predicted in relation with FSI and Compactness (figs 11-4 and 11-5). The demand tends to increase with lower FSI values and with greater envelope's exposure (high compactness ratio). In Barcelona, the relative weight of the FSI is lower as it can be noticed by the marked horizontality of the energy isolines. In this case, compactness becomes the key parameter to define the heating load. However, the two spatial parameters show a close correlation, especially for London samples. The likelihood of a high compactness ratio is notably greater for a low FSI.
- Domestic lighting loads are, instead, best predicted from the combination of FSI and GSI (fig 11-6), since compactness is less relevant for daylight than it is for thermal performance. The diagram has, as in the previous case, a high predictive potential and it presents an average error of 6% in the thirty four observations that were plotted. The climatic context does not produce substantial differences because the analytic method does not account for the different frequency of sunny skies in London and Barcelona. When daylight factor is calculated in the UEI, sky is assumed to be uniform or overcast. For this reason, the same graph can be used in the two cities. Unlike heating loads, lighting is strongly penalized with the increase of FSI and, especially with high GSI. Variations up to 60% can be found among the analyzed samples.

11.2.1 Domestic heating in London Docklands and Barcelona Poblenou: before and after Urban Regeneration

The outcome from the previous analysis was carried forward to calibrate the GIS version of the UEI model in London and Barcelona. The seventeen samples of each city were added to those from chapter 6 and used to obtain the correlation between spatial variables and energy performance. In a multiple regression analysis FSI, GSI and compactness were the independent variables to find the heat load as the dependent one. It enabled the assessment of large urban areas and the estimation of variations on energy intensity across the city and/or over time.

The first enquiry undertaken with this method looked into the evolution of heating demand along the urban transformations in Poblenou and Docklands. This seemed a logical step as one of the main arguments from compact city theory states that archetypical urban housing are more energy efficient than rural and suburban accommodation.

Examples from the previous section (assessment of urban typologies) can be taken as reference values. A preliminary evaluation can be performed by identifying similar typologies in the pool of samples. In this way, it can be found a certain similarity between samples B7 to B9 and the residential fabric at Poblenou. Consequently, the expected performance should range between 9 and 18kWh/m². Likewise, the housing stock in Docklands 1981 was formed by a combination of terraced houses (samples L10 to L12) and council blocks (L14 L15). Therefore, the potential heat load should be within the order of 75kWh/m².

Two sets of simulations were done for each case study: the first one considered the physical context as it was before the regeneration, this is in 1981. The second simulation assessed the current state in both districts. Although all constructions that were on site have been considered in the models, results were filtered to extract values only from residential buildings[13]. Once more, the object of the analysis was the urban form, which means that specifications at building level were kept constant[14]. As it was expected, domestic energy load increased notably, in absolute terms, after the renovation. This is a consequence of densification, as more residents have settled in those areas. However, as long as the relative consumption (per head or square meter) proves more efficient than alternative locations, it could be considered as a positive strategy.

In London Docklands the total heating load increased over 200% (fig. 11-8) between 2012 and 1981, due to the new residential developments. The new urban typologies were, in principle, more efficient. The average of the housing stock is 71kWh/m² in 2012 versus 73kWh/m² in 1981. However, since the ratio of persons occupying each dwelling has descended in the new schemes[15], the mean load per resident has increased almost 50% (from 1,605 to 2,431kWh/person year).

12 A full list of the model parameters can be found in Appendix I and in chapter 6

13 Including other building types would add much greater uncertainty due to broader heterogeneity in internal conditions and it would not allow clear comparisons.

14 Full details in appendix 1

15 HATC Limited, 2006 Gleeson, 2011

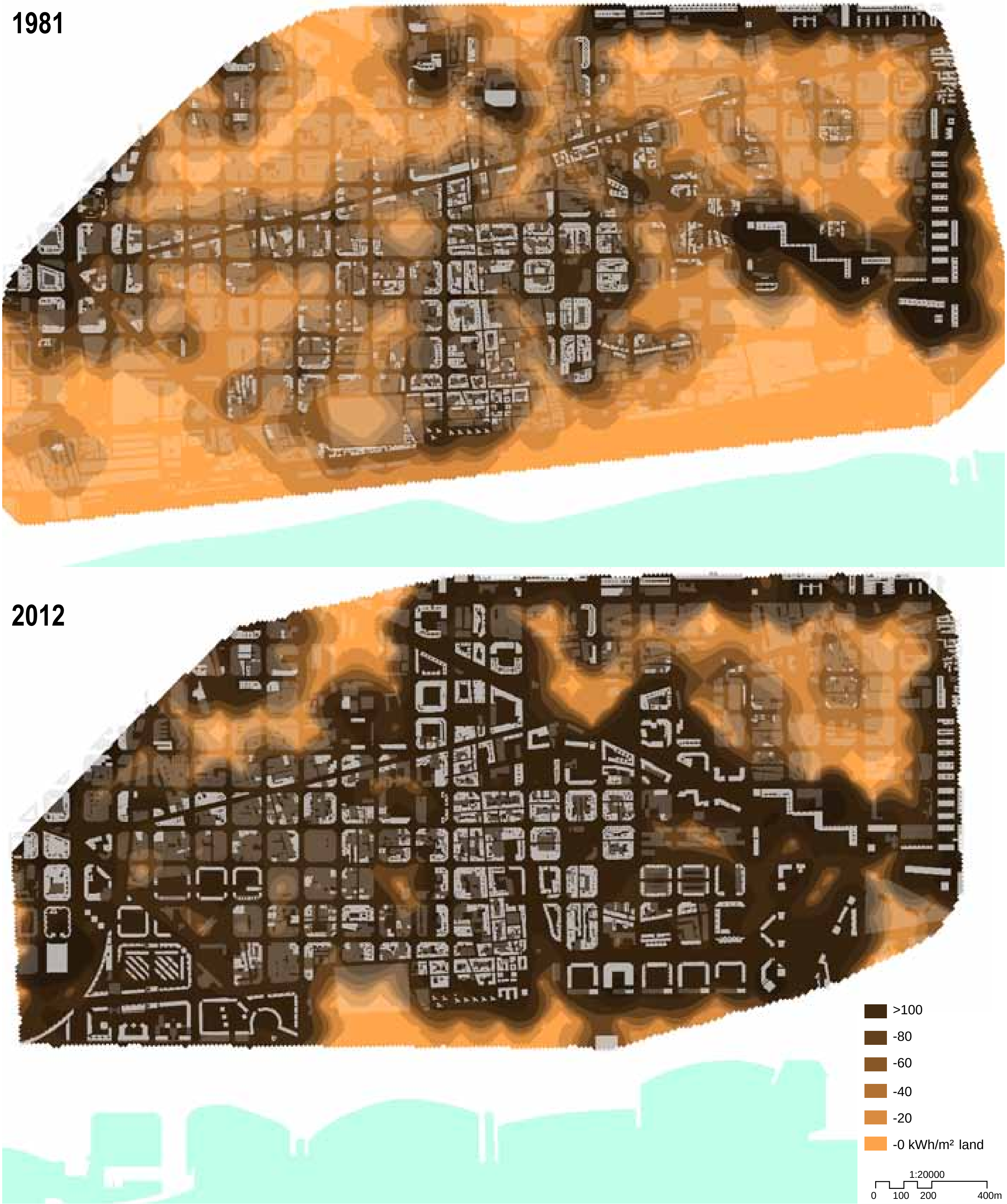


Fig.11-7 Interpolated domestic heat load density at Poblenou before and after regeneration. Units are expressed as average heat load per square meter of ground area

Similar patterns can be found at Barcelona Poblenou (fig. 11-7), where the total domestic heat load increased in 260%. In this case, the performance of the new urban typologies did not improve the existing ones (from 13kWh/m² in 1981 to 18kWh/m² in 2012). Probably, due to the fact that the housing stock was formed by compact buildings in 1981 and the replacement types where, in fact, more exposed[16].

So far, there is no clear evidence that suggests that energy efficiency has improved in these inner city locations. It is only when these figures are compared against the performance of typical suburban developments that the saving potential of urban compaction emerges. Looking at the initial samples (figs. 11-2 and 11-3), this comparison can be drawn. In Barcelona, samples B14 and B16 can be considered as the "business as usual" alternative to the densification of Poble Nou. The average heat load for those cases is around 30kWh/m², this is, 60% higher than the predicted average in the Poblenou after regeneration. In London, that difference is not so substantial, since suburban types tend to adopt semidetached and terraced typologies, which are not as exposed as detached dwellings. Furthermore, some of these types are also present in Docklands' newer schemes. As a result, the comparison between Docklands and sample L13, as representative of suburban types, shows that average domestic heat load is potentially 15% lower in the former.

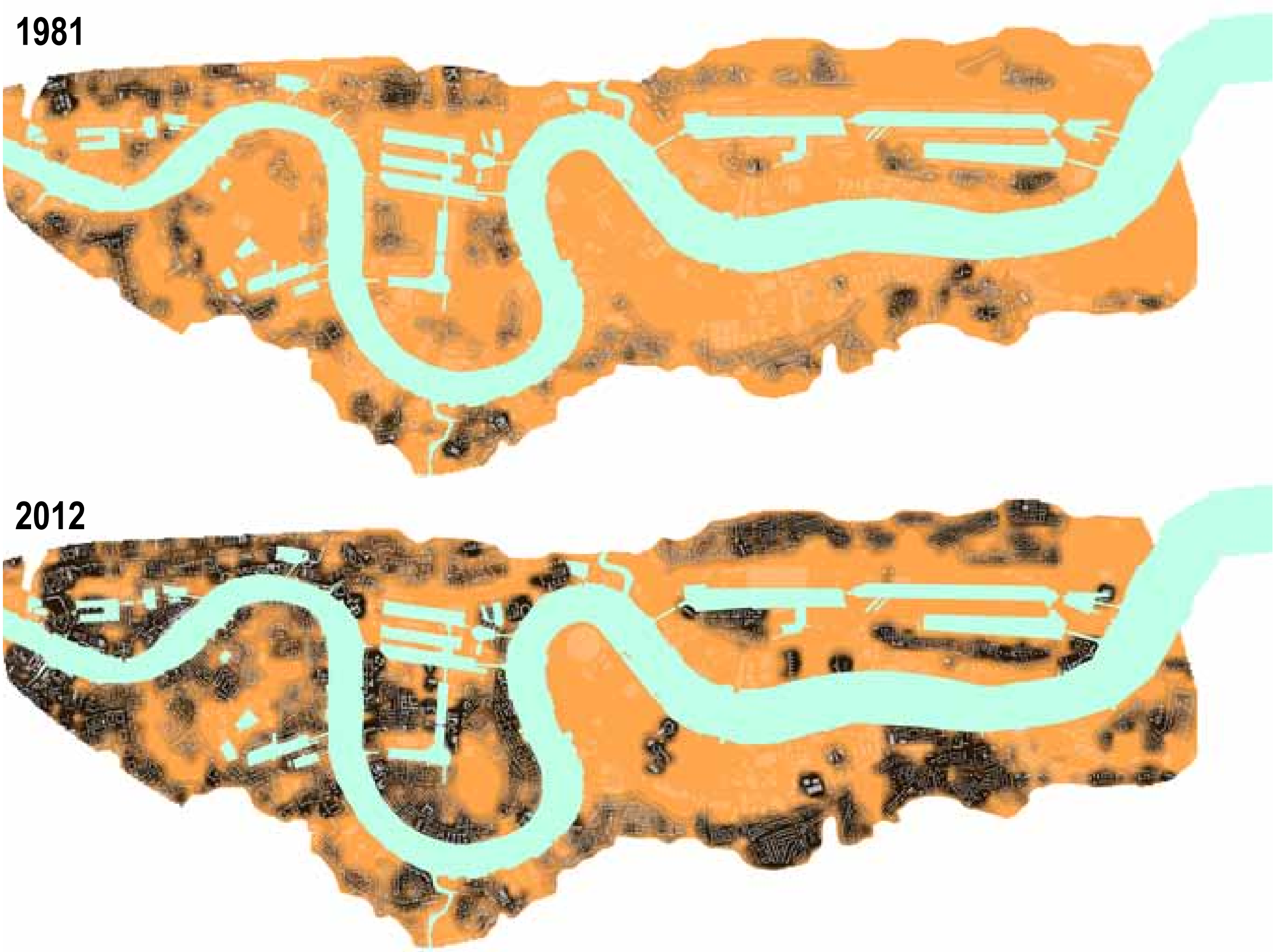
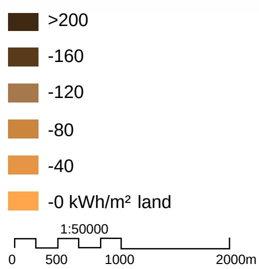


Fig.11-8 Interpolated domestic heat load density at London Docklands before and after regeneration.



16 In addition, it has to be admitted that the analytic method is presenting a distorted image of old buildings, since their materials and construction elements were of a much poorer condition and higher conductivity than that used for the simulations It was considered a legitimate assumption to center the analysis on the physical urban structure thus reducing the number of variables into play.

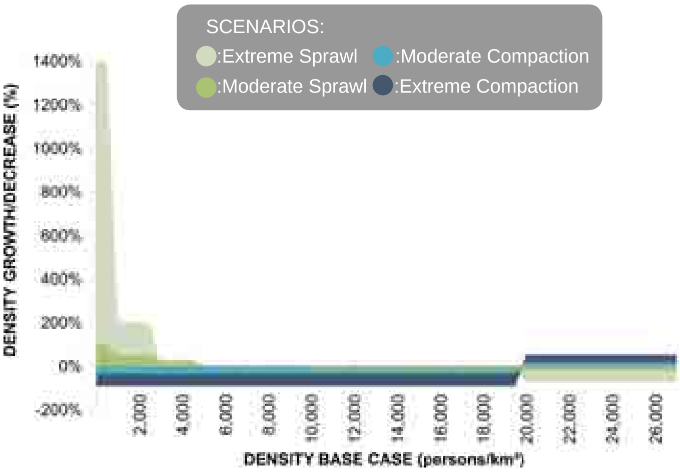


Fig.11-9 Relational functions used to create the scenarios. The new density distribution was based on the current state and a proportional growth/shrinkage

Table.11-1 Relational factors for different density ranges and scenarios

		Density (D) p/km²					
		D>20,000	10,000<D<20,000	5,000<D<10,000	3,000<D<5,000	1,000<D<3,000	D<1,000
LONDON	Case 1	D*0.3	D*0.4	D*0.5	D*2.5	D*8	D*14
	Case 2	D*0.7	D*0.7	D*0.9	D*2	D*3	D*6
	Case 3	D*1.8	D*1.6	D*0.7	D*0.7	D*0.7	D*0.7
	Case 4	D*2.23	D*2	D*0.1	D*0.1	D*0.1	D*0.1
BARCELONA	Case 1	D*0.3	D*0.8	D*0.9	D*0.95	D*3	D*15
	Case 2	D*0.8	D*0.8	D	D*1.3	D*1.5	D*2
	Case 3	D*1.2	D*0.65	D*0.65	D*0.65	D*0.65	D*0.65
	Case 4	D*1.5	D*0.1	D*0.1	D*0.1	D*0.1	D*0.1

11.3 Domestic Heat Load and Urban Form: speculations

After a broad range of urban typologies has been related to their thermal and lighting performance, and that the different behavior of rural, suburban and urban environments has been established, it is possible to elaborate further enquiries about the influence of the urban form in overall energy patterns. In the speculative formulations, the starting point is the current urban structure. Potential scenarios of urban evolution will be drawn in two opposite directions. On the one hand, it will be assumed that decentralizing forces are producing a gradual relocation of the urban population towards the periphery. It replicates the prevailing trend of the last quarter of the 20th century. On the other hand, alternative scenarios will be based on the hypothetical concentration of population in the main built up areas, following the precepts of compact city theories. A total of four scenarios were created, in addition to the base case, in each urban region (London and Barcelona). The scenarios can be divided in two main categories: sprawl and compaction. In each category, one case would represent a moderate degree and the other case would represent an extreme situation. It was understood that these four steps would give a clear idea on the level of transformation that would be necessary to induce a significant impact on energy performance patterns. Domestic heating load was again used as key performance indicator in all cases. Scenarios were modeled in GIS and assessed using the GIS version of the UEI.

11.3.1 Scenarios: compaction and sprawl

Unlike comparisons in Docklands and Poblenou, population was a fixed parameter. Cities would not grow or shrink in demographic terms, but they would only modify their spatial distribution across the metropolitan region. This premise aimed to demonstrate the ambiguity of average density as a morphological parameter at urban or regional level. In all the analyzed scenarios, population and, therefore, average density were kept constant but totally different urban structures were, nonetheless, produced.

The method to create the scenarios was systematized by means of boolean operations embedded in simple algorithms. Every unit of land would evolve from the base case to each scenario in a way that was defined by the initial conditions of that unit of land and the operator that corresponded to that condition in the algorithm. The scenario's construction process can be summarized in the following steps:

- Essentially, the starting point was a population density raster map with a cell resolution of 100m (each cell was equivalent to 100x100m of real land). The value associated to each cell was the total population living within the cell, which gives a population per 100x100m, this is, population per hectare.
- Each cell of the map would be multiplied by a factor that depended on the initial density of the cell. Typically, in scenarios of urban compaction, the density of cells above a given threshold would increase to absorb the population that was subtracted from cells with lower initial density. Conversely, in scenarios that simulated urban sprawl, density of cells above a given threshold would be reduced and the redundant population would be sent to cells with low initial density, thus increasing the proportion of suburban population (fig. 11-9 and table 11-1).

In total four scenarios were generated:

- **Scenario 1. Extreme sprawl**: there is a massive flow from urban areas to the suburbs. The density at the city centre decreases about 70% while increasing in rural settlements that have less than 50 persons per hectare
- **Scenario 2. Moderate sprawl**: density at the core city decreases between 20 and 30% while moderately increasing in the suburbs
- **Scenario 3. Moderate compaction**: density at the core city increases between 20 and 80%. It decreases about 30% in all other areas
- **Scenario 4. Extreme compaction**: about 90% of suburban populations moves to the inner city, thus increasing density in central districts between 50 and 110%

The specific conditions to shape the scenarios are illustrated in figures 11-9 and table 11-1.

11.3.2. From density distribution to heat index

The process to elaborate estimations for each scenario was based on the assumption that the prevailing urban typology in each zone would still be the prevailing typology after the transformation. In the case of densification, the new fabric would retain its initial characteristic attributes. In this way, a rural settlement would get denser by adding new detached housing, or a similar typology, to the existing ones instead of adding, for instance, housing blocks. Conversely, urban zones would accommodate potential new population in housing blocks. Although this may not reflect all possible situations, it was considered the most appropriate way to represent the most likely cases. In addition, domestic heal load could then be estimated as a function of the residential density and the heating performance of the urban fabric in each zone.

An specific method was devised to obtain region-wide estimations on energy performance from the available data and the UEI GIS application. This method consisted on four layers of information and analysis (fig. 11-10):

- Layer 1: The starting point was the existing built up fabric. Information of the buildings' footprint and height in the urban region was compiled, cleaned and verified.
- Layer 2: The UEI GIS application was operated on the three-dimensional cartography of the urban fabric, obtaining a reference value that would provide an average heat load per square meter of residential area for each cell of 100 by 100 meters (kWh/m² of built up area). This value considered every built structure, residential or not, for the calculations. The obstructions exerted by the overall fabric were, therefore, taken into account. However, to come up with a more realistic result, the output obtained at this stage was later filtered so as to compute only domestic heat load.
- Layer 3: The third layer was the residential density of each scenario (persons per hectare).
- Layer 4: The fourth layer was created by combining residential density and information about the average living space per person. The resulting layer was used as an approximate value of residential built up area for each cell. References on space standards were found at borough scale in London[17] , where living area per person ranges from 18 to 67m². As for Barcelona[18], only an average city-wide reference of 32 m² per person was found.
- Result: Finally, the layer map with information on residential built up area was multiplied to layer 2, in order to find the absolute domestic heat load per cell (i.e. per hectare). The summary statistics of the resulting map could then be extracted to find the total domestic energy

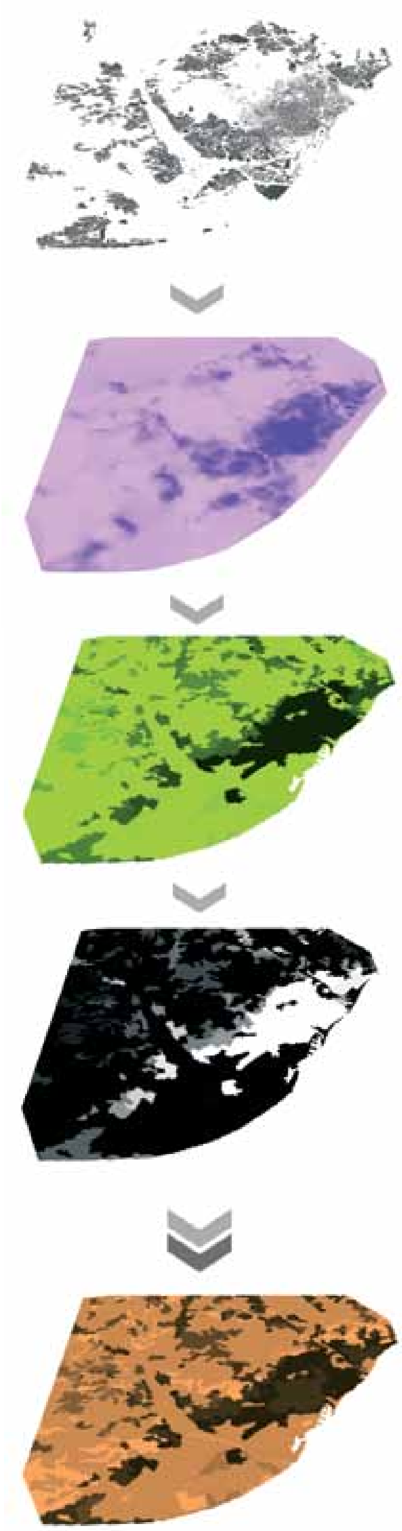


Fig.11-10 Layers of enery analysis, from top to bottom: building cartography, urban energy index (kwh/m² built up area), residential density (ppha), residential built up area (m²/ha) and, finally, domestic energy density (kWh/m² land area)

17 Gleeson, 2011
18 Urban Audit, 2004

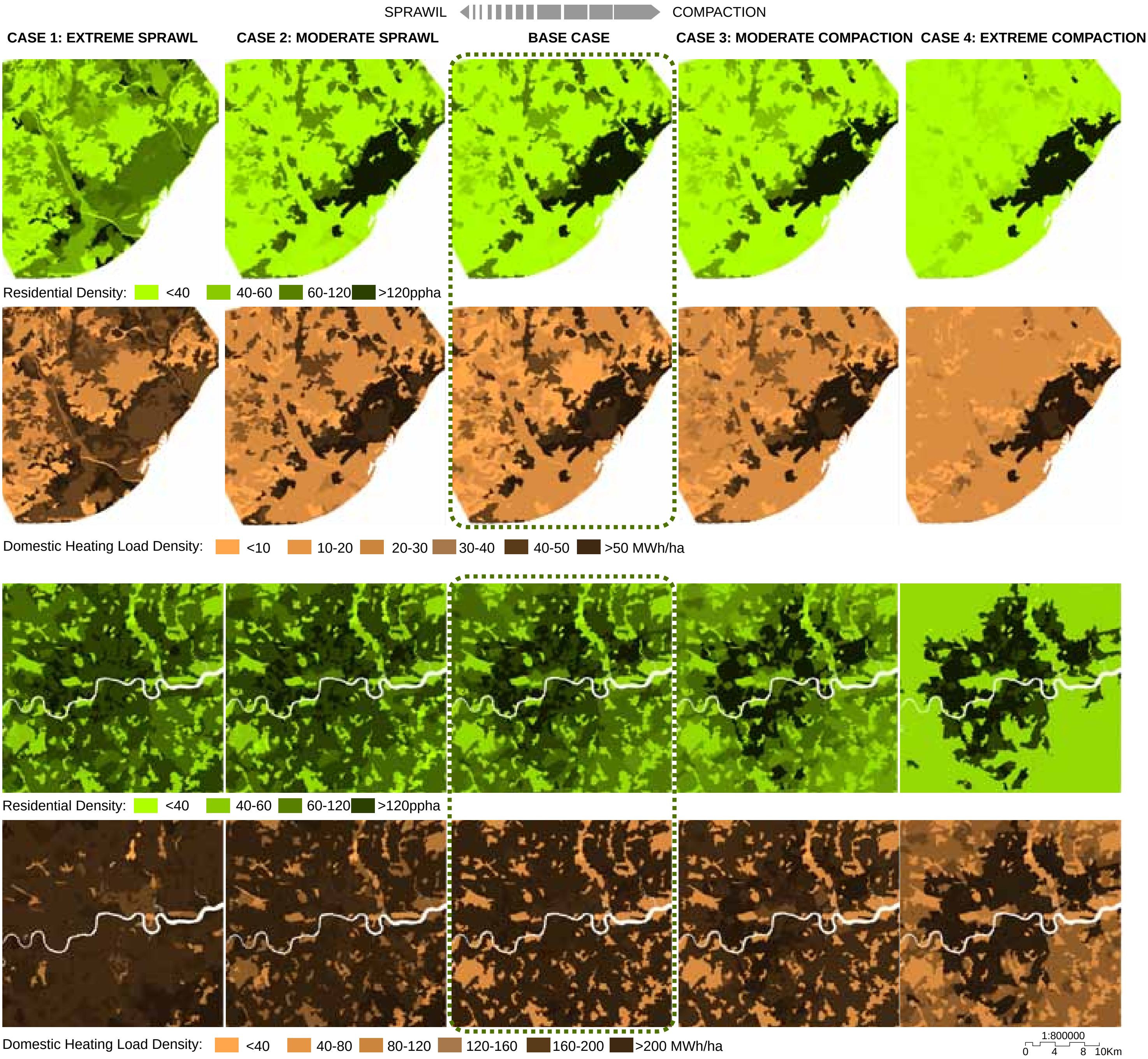
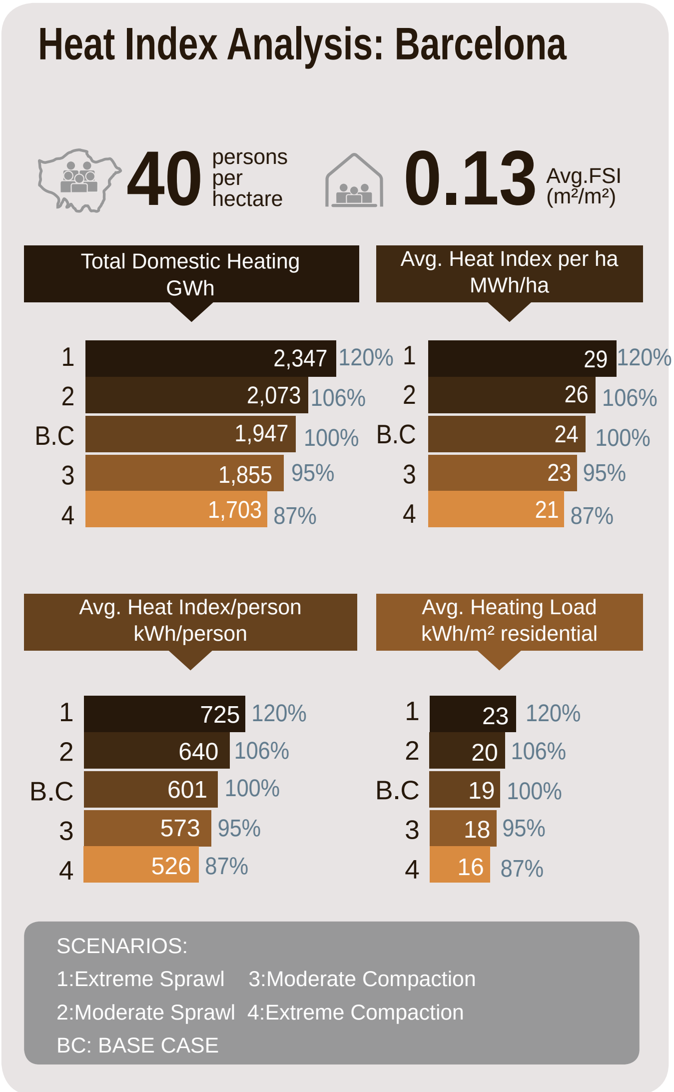


Fig.11-11 Energy maps resulting from the assessment of the base case and four scenarios. Top: Barcelona. Bottom: London

demand on the region and derive the relevant parameters (e.g. average heat load per habitant or heat load per square meter...)

11.3.3 HEAT INDEX: results analysis

According to the findings from this analysis, there is a correlation between urban compactness and domestic heating load. The scenarios depicting urban sprawl show higher consumption than those representing urban compaction. A pattern that is also consistent among different degrees of expansion or containment. The dimension of the potential savings or penalties varies for the two urban regions:



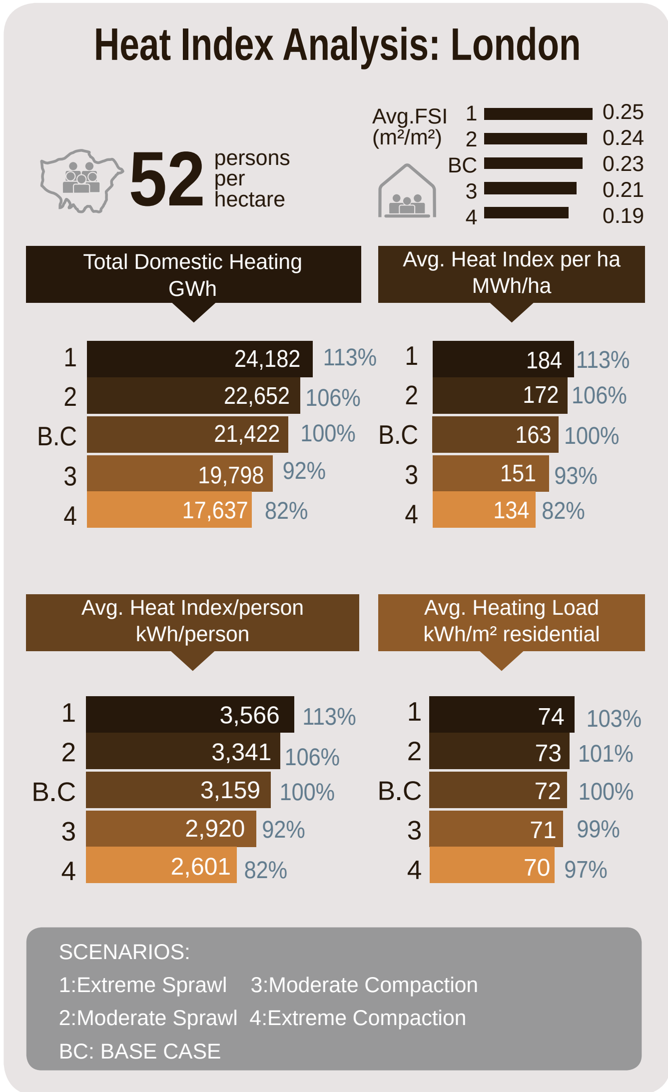


Fig.11-12 Summary statistics from urban energy analysis in Barcelona and London

- In Barcelona, the most efficient urban structure is associated with a reduction of 13% respect to the base case. It has to be pointed out that for these relatively modest savings, the central districts had to double their density. This is a drastic measure for a moderate yield. The relative convenience of densification becomes clearer in scenario 2, in which a density increase of 80% in central districts has hardly delivered a 5% energy reduction. The scenario of maximum dispersion requires, in principle, 21% more energy to satisfy space heating needs, whereas moderate sprawl is penalized with an increase of 6%.

- In London, absolute values are larger. This is a consequence of the colder climate, larger population and building stock. Since in this case, the living space per person was broken down for each borough, the percentage variations in the mean heat load per square meter of dwelling space and the other variables differ. In fact, taking the average heat load would only show a small difference, around 5%, between the best and the worst performing cases. However, the other indexes present larger variations, about 30%. Compared to the base case, the scenario of extreme compaction would deliver potential savings up to 17%, whereas the extreme sprawl results in 13% more energy usage.

The followings conclusions can be extracted from this analysis:

- Although urban typologies based on low density tend to penalize domestic heat load, the scope for improved efficiency based on urban form is relatively little.
- Indeed, further savings could be achieved by less drastic solutions (insulation, air tightness...) or by means of architectural design (orientation, openings...) Studies at building scale have shown a greater saving potential by implementing retrofitting measures in the buildings envelope[19]
- Furthermore, the reduction in space heating could come with an unintended increase of lighting energy. As it could be seen in figure 11-6 (UEI lighting diagrams), the energy required for lighting tends to increase with density (FSI) and ground coverage (GSI). It could end up by offsetting potential gains.

However, the case for urban compaction has been built upon other arguments, such as travel, which will be explored in following paragraphs.

11.4 Personal Travel and Urban Form: speculations

Transport has been commonly referred as the single variable whose energy consumption is most influenced by urban form. A number of studies were critically reviewed in chapter 5. Those key reports, both theoretical and empirical, showed a consistent connection between residential density and transport energy (fig. 5-14). The aim of the following analysis is to discern whether the densification processes in Docklands and Poblenou induced an actual reduction in travel. Ideally, current travel surveys would be compared with data from a period before the regeneration. However, this was a difficult task due to the unfeasibility of detaching the effect of urban renewal from other factors, such as the socioeconomic context, road construction or, as it was the case in London, the implementation of a congestion charge. An alternative methodology was to analyze the evolution of traffic flows and recent travel patterns to derive a predictive model that could be applied to the scenarios created in the previous section.

11.4.1 Mobility Flows in London

Traffic was already perceived as an environmental problem in the London of the 1930s, not because of fuel consumption or CO_2 emissions, but due to increasing number of accidents and the inability of the outdated road network to absorb the intense traffic flows[20]. London's physical expansion was strongly linked to the development of the underground and suburban trains[21] but the most popular means of travel were

Fig.11-13 Road network and traffic densities in Greater London around 1937 (redrawn with data from Abercrombie, 1945)

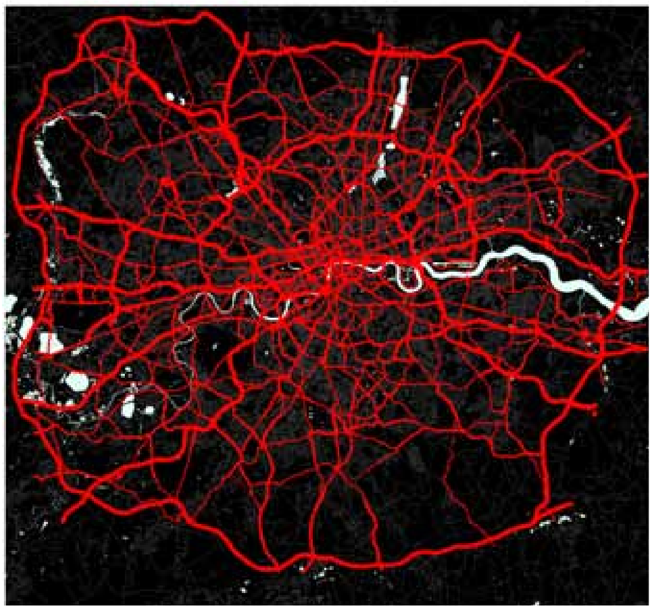


Fig.11-14 Road network and traffic densities in Greater London in 2010 (redrawn with data from Brady, 2012)

19 Rodríguez Álvarez, 2008
20 Forshaw & Abercrombie, 1944
21 Rasmussen, 1937

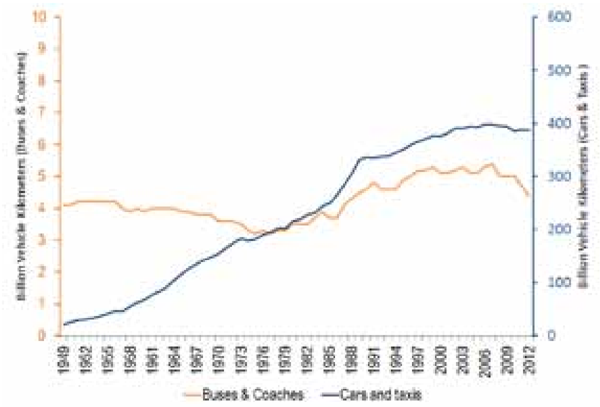


Fig.11-15 Road Traffic (vehicle kilometers) by main vehicle types in Great Britain from 1949 (data from Department of Traffic, 2013)

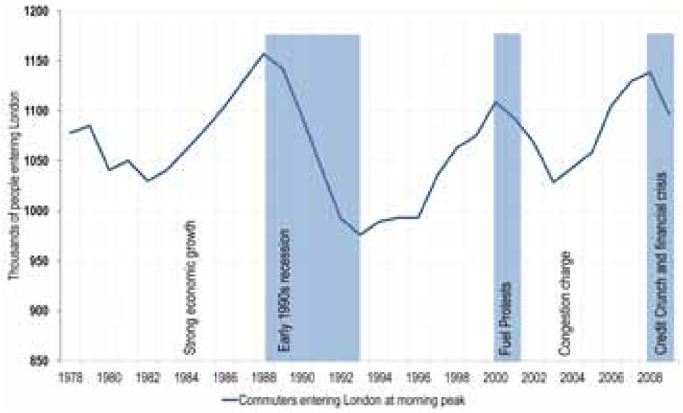


Fig.11-17 Total commuters entering London at morning peak from 1978 to 2008. Related socioeconomic events (data from Transport for London, 2010)

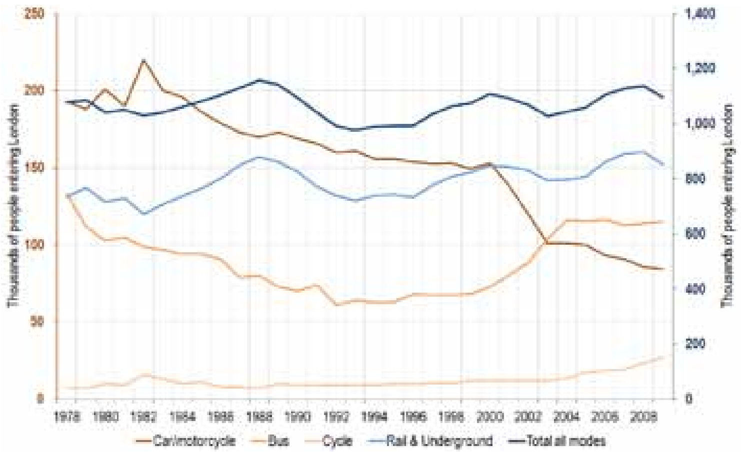


Fig.11-16 People entering central London in the weekday morning peak from 1978 to 2009 by main transport modes (data from Transport for London, 2010)

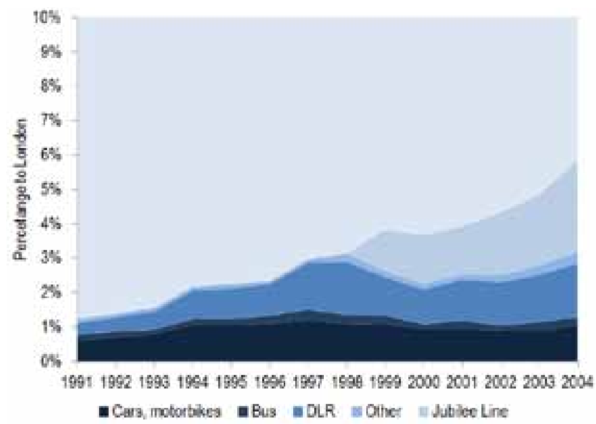


Fig.11-18 People entering the Isle of Dogs at morning peak as percentage of London traffic flow by mode of transport (data from Transport for London, 2005)

still based on road systems (coach, tram and bus).The road network has evolved in an spider-web structure formed by a system of thoroughfares (fig. 11-13). After the World War II, the rising number of cars in the streets and the precedents from the American experience stirred plans to adapt the city to the new traffic era. Abercrombie's plan for the London County proposed a new road system which included three ring roads for fast traffic inserted in the built fabric. It would have implied new viaducts, elevated roundabouts, street widening and the kind of road engineering that spoiled so many cities from the ninety sixties onwards. Those plans were never implemented and the ring roads were sent to the green belt, some 25km from the centre (fig. 11-14).

The predicted popularization of the car led to an spectacular growth in road traffic during the postwar until the 1970s (Fig.11-15). The car became a strong competitor for London buses, as well as an obstacle to their efficiency. On the one hand, it displaced an important proportion of users while, on the other one, it contributed to enhance traffic congestion thus slowing buses down. The decline of the bus was filled by the increase of the railway, which became, in combination with the underground, the prevailing commuting mode to and from central London (fig. 11-16). From the late 1990s and after the liberalization of the service, bus lines started to recover from their steady fall. At the same time, car traffic suffered a step decrease in central London. Unlike other parts of the country, the use of the private car was decreasing every year since 1982. The most probable reason had to do the high level of congestion and the increasing unaffordablity of parking at the centre. In 2003, a Congestion Charge came into effect for all vehicles entering Central London during working hours. The standard tariff is currently 10 GBP per day (almost 12 Euros) and it applies within an inner ring that spans from London Tower to Edgware Road, down to Vauxhall Bridge in the north bank and Elephant and Castle and Tower Bridge in the south bank.

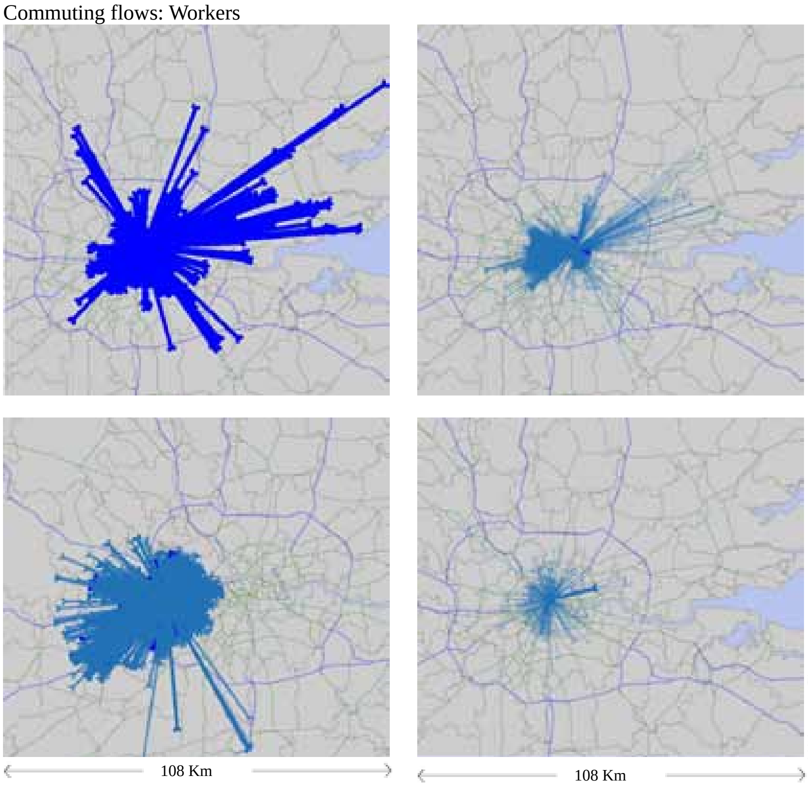


Fig.11-19 Commuter flows to four key employement nodes in London, from top let, clockwise: the City, Canary Wharf, West End and Heathrow (Source: 2001 Census, CommuterView)

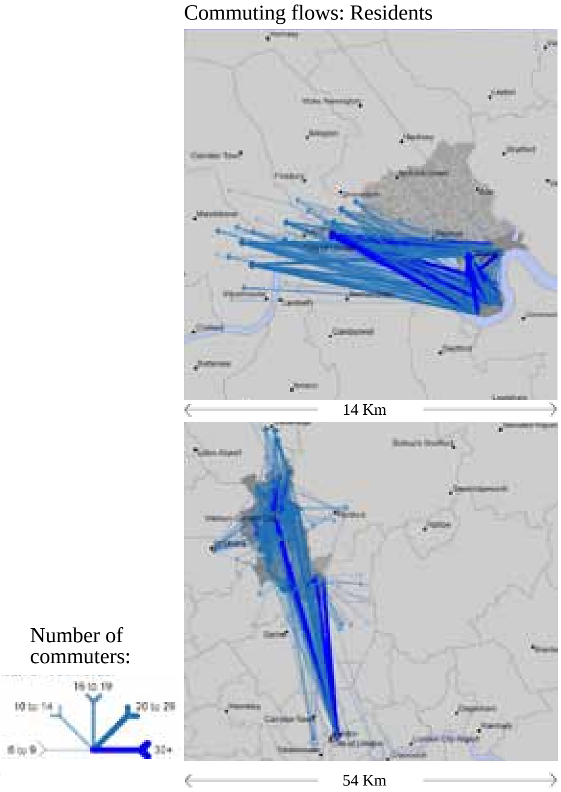


Fig.11-20 Commuter flows from residents of the Isle of Dogs (top)and Welwyn (bottom). (Source: 2001 Census, CommuterView)

This measure produced an almost instant reduction of 30% in the number of cars entering the city at peak times (fig. 11-16). The overall flow of commuters did not decrease though, as buses absorbed most of the passengers that gave up to private car. Interestingly, an old system has become a new alternative to the traditional modes, as cycling has experienced a notable increase in the number of user since 2004.

As expected, is difficult to quantify the influence of Docklands in these patterns from the observation of general data. On the one hand, there was an new demand generated by the concentration of jobs in the area, especially at Canary Wharf. This would be the easy part, as data regarding commuters to the Isle of Dogs is readily available (fig. 11-18). On the other hand, Docklands, as inner residential location, enables smaller commuting distances for their residents as compared with typical suburbs, which may traduce in smaller carbon footprint on travel.

The analysis of travel data from 1978 denotes the little potential of the redevelopment of Docklands. Commuting patterns remain unaffected throughout the period. Moreover, they are more related to the economic context (fig. 11-17). During times of affluence, the number of commuters grows, while it falls after a crisis or in recession periods. The causal relation is obvious, as the destruction of jobs derives in redundant workers ceasing to travel. Following this logic, it could be argued that Docklands indirectly induced an increase in travel, associated to the new positions that were created. The number of commuters entering the Isle of Dogs has increased by a factor of six in the last decades, from an average of 13,000 persons at weekday peak time in 1990 to over 64,000 in 2004. The figure in 2004 represents 6% of the overall commuting flow to London (fig.11-18) for about 5% of the labour force. According to this figures the attraction exerted by Docklands as employment centre is slightly stronger than the average in London but smaller than for other traditional working centrers, such as the City or Heathrow.

The almost 200 thousand jobs that were created in the area were nearly matched by an influx of 140 thousand new residents. The ratio is 1.2 jobs per habitant, which is slightly high. Even assuming that all the local population could find a job in the area, almost 50% of the jobs would need to be filled by people from other locations. According to the census 2001, less than 20% of residents in the Isle of Dogs worked within the borough of Tower Hamlets and a similar proportion of the workforce have a permanent residence in the arrea. Although a higher degree of self-containment would be preferable, the

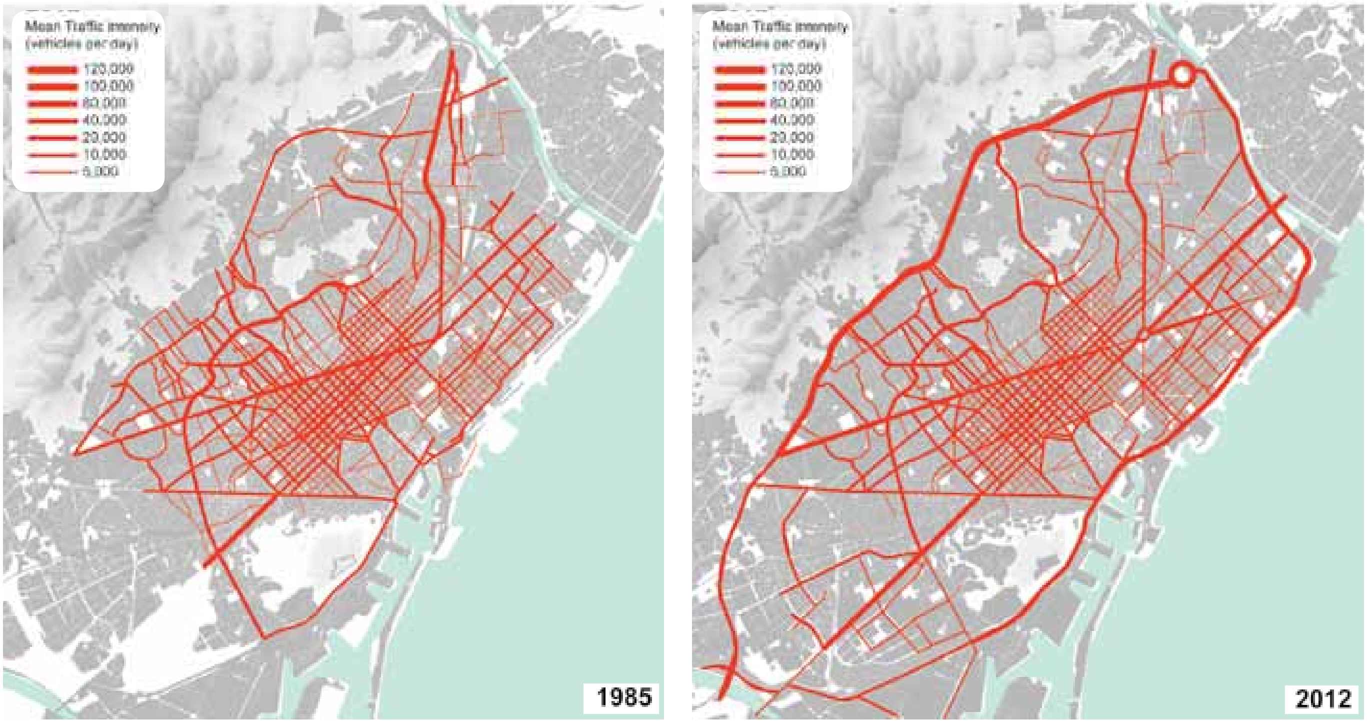


Fig.11-21 Left: Road network and traffic densities in Barcelona Metropolitan Area 1985 Right: Road network and traffic densities in Barcelona Metropolitan 2012 (contains data from Ajuntament de Barcelona, 2012)

1:100,000
0 1.5 3Km

comparison with suburban developments is still favorable to infill locations. Looking into the commuting connections (fig. 11-19 and 11-20), it can be noticed that a great majority of the residents of the Isle of Dogs work either in the City, Westminster or other central boroughs. It means that the commuting distance (about 8 to 10 km) is, in principle, smaller than for a suburban resident, who may need to cover, say the 40 km between Welwyn and the City (fig. 11-20). Regarding the working population, the new financial center works in a similar fashion than the other employment hubs of London. Workers are attracted from a catchment area that extends over a radius of 25 km. The main flows are generated from the inner boroughs (Islington, Camden, Kensington...) and the number of incoming commuter reduces drastically beyond the M25 (fig. 11-19), except for some areas to the northeast. Compared to the traditional working destinations, the flows at Docklands were not yet as intense as in the City[22] or Heathrow but they were relatively contained while it has outstripped Westminster and the West End.

11.4.2 Mobility Flows in Barcelona

Barcelona had fallen behind in terms infrastructure provision during the first half of the dictatorship. However, the intense urban and demographic expansion that started in the sixties demanded an ambitious plan to catch up with the increasing needs of access and mobility. A network of radial highways was laid to connect the city with its metropolitan area. Unlike London, topography was a critical limitation for the design of transport networks. The new infrastructure followed the path of the original roads and railways, along the coastal plane and the valleys between the mountain ranges. The connection between the urban streets and transit roads remained unresolved, thus the former became thoroughfares, introducing massive traffic flows to the core of the city (fig.11-21). The advent of democracy and the Olympics were a new impulse and the opportunity to undertake a ring road system that could alleviate internal traffic. The general implementation of private concessions to finance highway

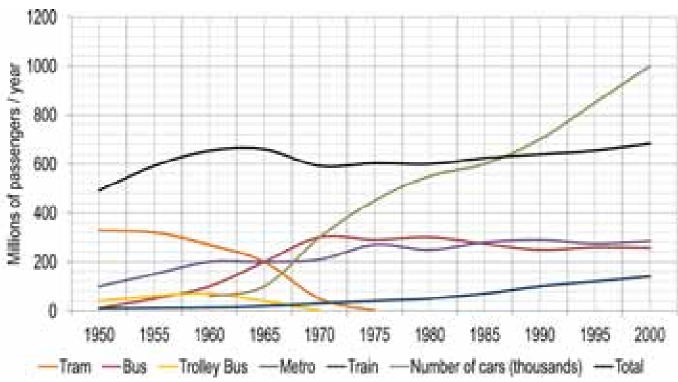


Fig.11-22 Evolution on the number of passengers per transport mode since 1950 (Ajuntament de Barcelona, 2008)

22 The data in the maps is from the Census 2001

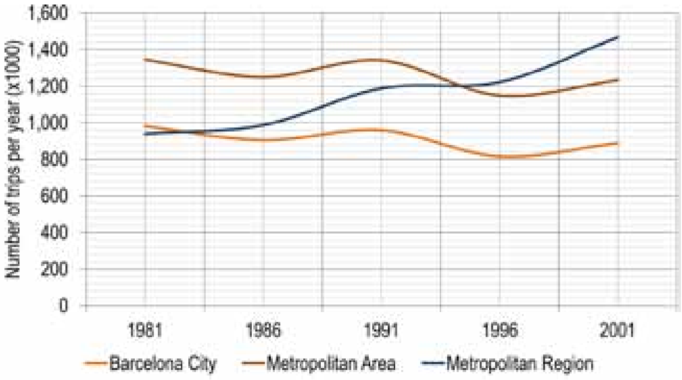


Fig.11-23 Decentralization of travel in the region of Barcelona (Ajuntament de Barcelona, 2008)

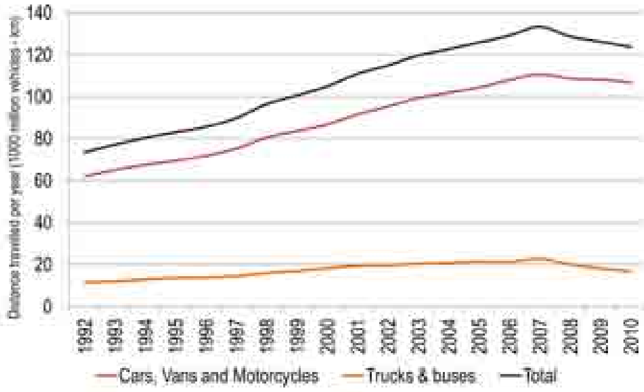


Fig.11-25 The rise of car traffic in Spain (Ministerio de Fomento, 2013)

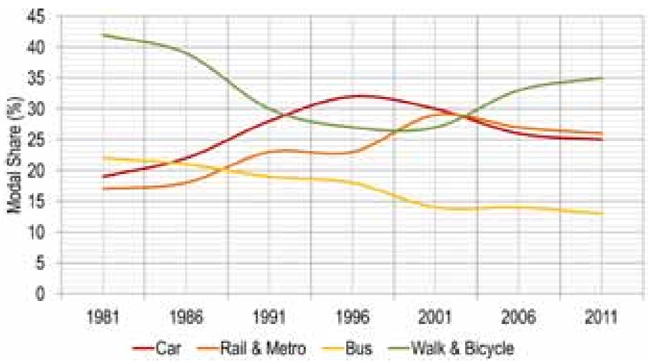


Fig.11-24 Modal share evolution in Barcelona (Ajuntament de Barcelona, 2008)

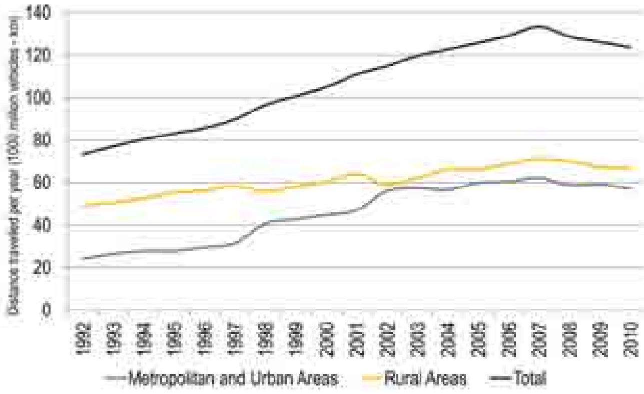


Fig.11-26 The intensification of road traffic urban areas in Spain (Ministerio de Fomento, 2013)

construction and the resulting tolls would, however, penalize metropolitan mobility and influence commuting patterns.

Until the Civil War, the tram was the prevailing transport mode, reaching over 300 million passengers per year. The bus replaced the tram in the postwar, which ceased to operate between the 1970s and 2004 (fig. 11-22), when it was reestablished in small sectors around the Olympic Village and Diagonal Avenue. During the seventies, the rise of the car was unstoppable and congestion at the city centre just escalated year after year (fig. 11-25). Car travel in urban areas has tripled in Spain in the last 20 years (fig. 11-26), this is a much greater increase than in rural areas. Public transport showed an inability to solve the traffic problem; the influx of passengers has remained stagnant since the early seventies. In 1997 a Metropolitan Agency was created to elaborate a new plan that contemplates the extension of existing metro, tram and suburban rail networks. Likewise, bus lines have been recently redefined to economize the routes and optimize their performance.

The urban expansion of the nineties was followed by an increase on travel within the metropolitan region (fig. 11-23). During this period, the car reinforced its position as the dominant transport mode in the overall region. The situation was reversed in the last decade, partly due to the opening of new metro lines and improvements in suburban trains (fig.11-24). More recently, the construction of cycling lanes has encouraged its massive use.

The satellite cities around Barcelona (Sabadell, Tarrasa...) have an economic importance and are poles of attraction themselves, which enhanced both a certain containment but also the creation of peripheral transit flows.

The impact of Poblenou on travel patterns cannot be directly interpreted from general figures either, as fluctuation in traffic intensity and commuting patterns result from a combination of factors, with a major influence of socioeconomic aspects. As in the case of Docklands, the redevelopment of the industrial district gets diluted in overall statistics by the small proportion that it represents within the urban region (2.3% of population and 3.3% of jobs). However, the potential decrease in travel needs can be understood by the observation of the patterns in the different areas. Travel data from 2006[23] was used to infer the different performance between the central districts and the suburbs (fig. 11-27). 25 municipalities of Barcelona Metropolitan Area were selected as samples and grouped into four categories:

23 IERM, 2006

- The municipality of Barcelona
- Towns in the first metropolitan ring: Badalona, Santa Coloma, Cornellá, Sant Boi, El Prat, L'Hospitalet, Sant Feliu
- Towns in the second metropolitan ring: Viladecans, Castelldefels, Sant Cugat del Vallés, Rubí,Cerdanyola del Vallés and Mollet del Vallés
- Satellite towns: Sabadell, Terrasa, Mataró, Vilanova i la Geltrú, Granollers and Vilafranca del Penedès

The insights from this analysis are twofold:

- Firstly, the degree of self-containment is stronger in Barcelona (fig. 11-31), where over 80% of the trips of the residents start and finish within municipal boundaries. Satellite cities reach 70%, whereas the suburban towns, both in the first and second rings show a lower 60% of self containment as they have a greater dependence on the main centers of activity.
- On the other hand, modal choice is affected by geographical location (fig. 11-31). While the probability of walking is similar in all locations, the residents of Barcelona show a greater preference for public transport (27%) compared to the suburban population (from 7 to 16%). The use of the car increases with distance to Barcelona. Even in satellite towns, despite their relative containment, there is a high dependence on private transport.

According to these data, the reversal of urban sprawl in Barcelona would present an opportunity to reduce the energy spent in transport. Therefore, the designation of new residential areas at Poblenou and other central districts, where densification is still possible, may eventually lead to actual reductions in travel related emissions. In order to evaluate and quantify the extent of those savings, deeper studies were undertaken, both in the regions of London and Barcelona.

11.4.3. Transport energy patterns in London and Barcelona

After having verified the modest savings from urban contention in space heating, the focus is now on travel performance. The aim was to establish a comparative analysis between central areas and the periphery, on the one hand, and between London and Barcelona on the other one. The initial hypothesis was based on theories that assume that residents of dense and central areas have less need for travel than residents of rural zones, who, by definition commute to further destinations. This statement was tested on the regions of London and Barcelona, using data from official travel surveys, which was processed and synthesized in thematic cartographies of the main indicators of travel in relation with energy.

11.4.3.1 Methodology

Due to different origin of data, there was a lack of homogeneity, both in the available variables and the compilation methods. In order to allow meaningful comparison, the information was processed to obtain an equivalent energy demand from travel in both regions. The assessment procedure was adapted to the specific information that was available in each case.

11.4.3.1.1 Barcelona

Data sources

The travel datasets selected for Barcelona studies were the following:

- Travel survey (commuting to work and study) by the Statistical Institute of Catalonia (IDESCAT)[24] based on 2001 Census. This dataset contains information related to commuting flows derived from mobility for working and studying purposes. Data regarding trip duration and the number of trips by mode of transport at municipal scale was provided. For each municipality, tables contain the number of trips in relation with four main destination types:
  - Destination within the same municipality
  - The 40 most frequent other municipalities that were destinations, disaggregated data
  - Trips to other areas in Catalonia region
  - Trips abroad
- The 2006 travel survey for Barcelona's metropolitan region[25] by the Institute of Regional and Metropolitan Studies of Barcelona. It supplies data regarding the modal share and self-containment for average weekdays and weekends in each municipality.
- Population density was obtained from the Cartographic Institute of Catalonia and IDESCAT[26]
- Jobs density and GDP were sourced from the Urban Mobility Plan by the Barcelona Council[27]

Calculation procedure

Two alternative calculation procedures were attempted to estimate the average distance travelled and the energy spent in personal travel by the residents of each municipality. The comparisons between the results from the two methods and of those with national and European studies provided a sound reference framework. In both cases, the main calculation steps were:

- The estimation of the number of trips per person. This parameter was supplied by travel surveys
- The average distance travelled per trip. It had to be

24 www.idescat.cat [last accessed 14.11.2013]
25 IERM, 2006
26 www.idescat.cat/pub/?id=aec&n=249&lang=es
27 Ajuntament de Barcelona, 2008b

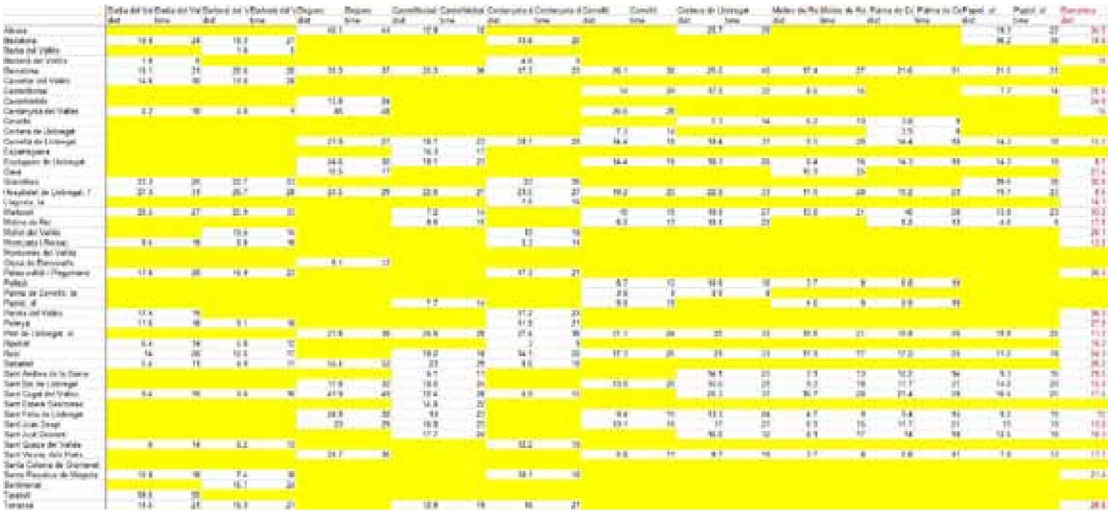


Fig.11-27 Part of the matrix showing the distances between the main towns in Barcelona Metropolitan Region

specifically calculated for each origin and destination as it was not provided by any of the reference documents

- The modal share. It was broken down in three categories and each category was accordingly subdivided into more specific modes:
  - Private transport: car, motorbike, other
  - Public transport: train, bus, other
  - Non motorized transport: walking, bicycle
- The energy efficiency of the different transport modes was obtained from general studies and adapted to the particular trip distribution in each zone[28]. A distinction was made between intraurban and interurban trips, assuming different vehicle speed and therefore different consumption levels.

The main difference between the two calculation procedures laid in the computation of the average trip length. The first calculation method consisted on the direct computation of the distance between origins and destinations according to the IDESCAT travel survey. A connectivity matrix was created to collect the distance, both in kilometers and time, between all the analyzed towns and the 56 most common destinations as shown in the survey. Distances were calculated as average road trips using Googlemaps and the "Get Directions" engine[29], which provides accurate estimates on trips by private car and public transport. Knowing the distance, the modal share and the number of trips to each locality, it was possible to calculate the average trip length in private and collective transport. The formula to do so can be represented as:

$$TD_i = \sum(NT_{i\text{-}j} * D_{i\text{-}j})/\sum NT_{i\text{-}j}$$

Where,

TD_i : Average distance for trips with origin i (km)

$NT_{i\text{-}j}$: Number of trips between origin i and destination j

$D_{i\text{-}j}$: Distance between origin i and destination j (km)

The average number of trips per person (NT) was given by travel reports, both for internal and external destinations. Therefore, the total distance travelled per person could be found as:

$$TT_i = TD_i * NT$$

Where,

TT: Total distance traveled per person (km)

NT: Average number of trips per person

In the second calculation method, the distance travelled was found as a function of the average trip duration, which was given by the 2006 travel survey for Barcelona's metropolitan region. An average urban speed was assigned to intraurban and interurban trips and per each transport mode as identified in the Mobility Plan of Barcelona Metropolitan Region (table 11-2)[30].The distance travelled was then found by multiplying the average trip duration per mode by the average speed.

The two methods showed consistent results, close to the data of oil consumption for the province of Barcelona as estimated in national accounts.[31] However, the second method was carried forward because it allowed a more detailed computation of all travel purposes, other than commuting, as weekend trips were also included.

Finally, the calculation procedure was applied to 20 municipalities within the metropolitan region in order to find the geographic distribution of[32]:

- The average annual distance travelled

28 The procedure to estimate fuel consumption can be found at ATM, 2008 Annex 2: Avaluació de les emissions

29 Example http://goo.gl/maps/h13A9 [last accessed 14.11.2013]

30 ATM, 2008

31 CORES, 2013

32 Calculations tables can be found at Appendix 1

Table.11-2 Average urban speeds from motorized transport modes (source: ATM, 2008)

Intraurban	Km/h
Bus	13.31
Metro, train	25
Tram	18
Cars, motorbikes & Vans	19
Trucks	20
Interurban	Km/h
Bus	27
Cars, motorbikes & Vans	36
Trucks	35
Train	60

- The average energy consumption used in travel
- The average travel budget (in Euros per person)

All these parameters were obtained as for the residents of each municipality

11.4.3.1.2. London

Data sources

The assessment of travel impacts in London was done in a different way due to the different nature of available data. Although the amount of information about London is overwhelming, a thorough selection was done to identify the most relevant data, found in the following key sources:

- The 2010 Travel in London Report, an study conducted regularly by Transport for London that includes detail accounts of the average distance travelled and modal shares at borough level[33]
- Borough Commuting Patterns, based on the Census 2001[34]. It provides an origin destination matrix for London boroughs and the most common destinations outside Greater London
- Flows of Commuters between Local Authorities, by the Office for National Statistics (ONS)[35]. It provides details of the origins and destination of commuting journeys in all UK. It is based on the 2001 Census data.
- National Travel Surveys, which are yearly conducted by the Department of Transport since 1988[36]. It provides information about average number of trips, trip length and modal share at regional and national scale

Calculation procedure

The procedure to estimate of fuel consumption in travel from residents across London boroughs and surrounding towns is illustrated by figure 11-28. The main input data, were readily available in the aforementioned sources. The average distance travelled was obtained from the Travel in London report. It was disaggregated in the main travel modes to find the distance travelled in each mode. Before applying fuel efficiency factors, distance was broken down into intraurban and interurban trips, so that the different vehicle performance could be taken into account. Finally the average fuel consumption was obtained by adding the energy usage for all modes. The average trip duration was likewise calculated, the only difference in the procedure was to replace fuel efficiency by average speed per travel mode and type of trip (intra or interurban) and the equivalent energy by the average travel time.

11.4.4. Mapping Travel Patterns in London and Barcelona

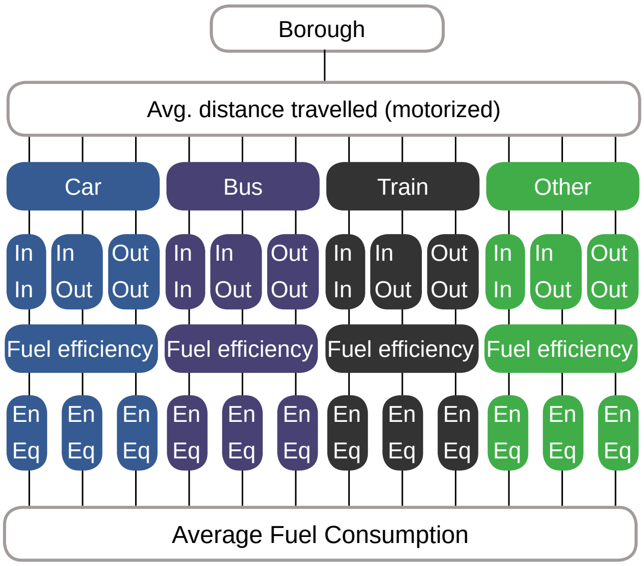


Fig.11-28 Fuel consumption calculation steps

Mapping travel patterns

A number of maps were plotted with these results to represent the geographic variation of travel patterns and its associated energy in Greater London and Barcelona Metropolitan Area. These maps were, therefore, based on surveyed data and the calculation procedures detailed in the previous paragraphs. As expected, there is a strong correspondence between the average length of commuting journeys and the equivalent energy use. In the case of London, distance to work for the borough residents was given as physical distance (fig. 11-29) whereas for Barcelona, journey length was given as trip duration.

Maps of equivalent energy used for personal travel were plotted as synthetic indicator of travel patterns. Energy units combines the effect of fuel efficiency, trip length, number of trips and modal share in one parameter. Although it is commonly reflected as fuel consumption, it has been converted to heating values according to the heat content of

33 Transport for London, 2010
34 ONS,2003
35 ONS, 2013
36 Department for Transport, 2013

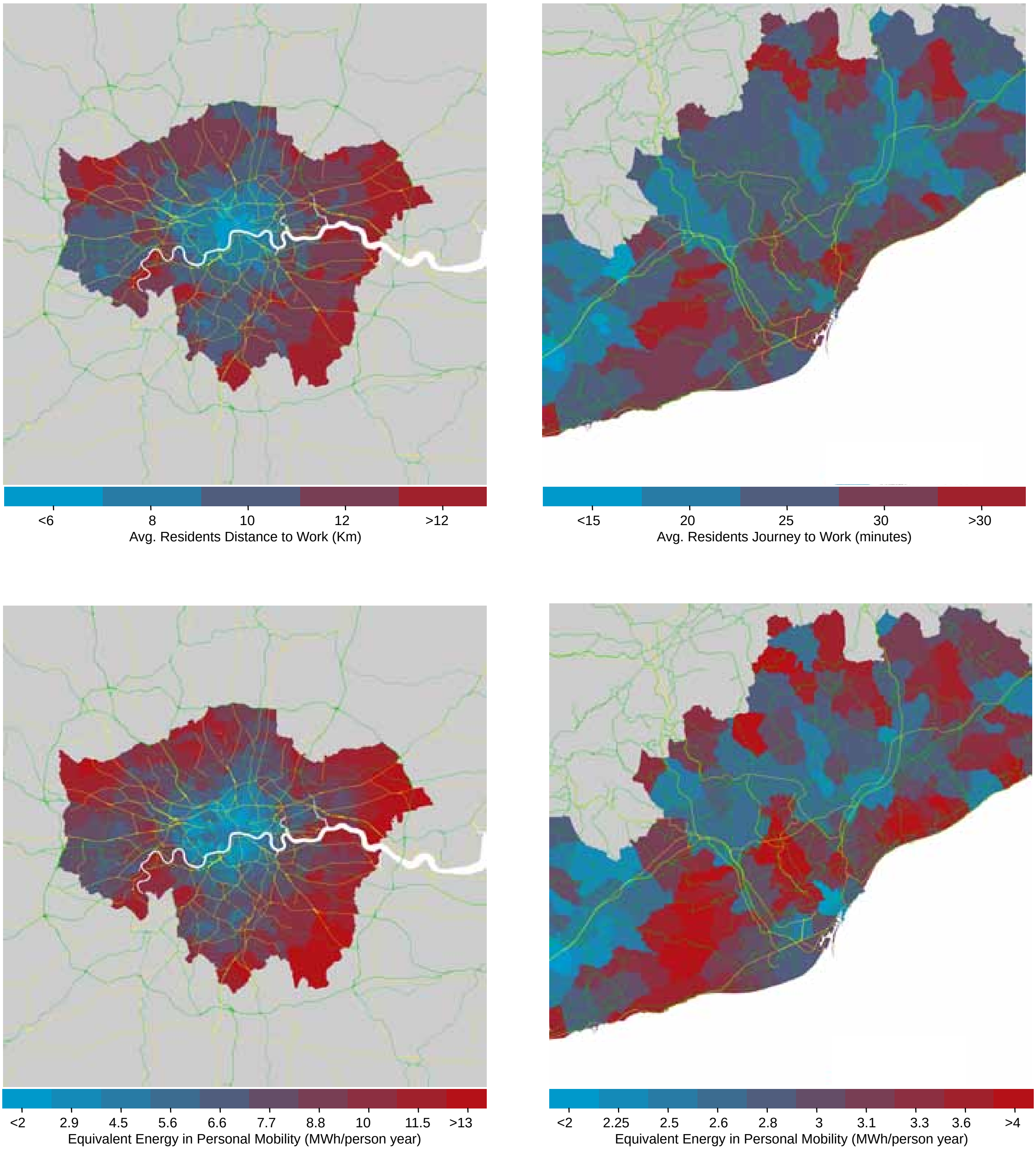


Fig.11-29 Top: Average journey to work lengths in Greater London and Barcelona Metropolitan Area.
Bottom: Average energy for travel per resident in Greater London and Barcelona Metropolitan Area

each fuel type. The final units are expressed as kWh, using conversion factors from the Transportation Energy Data Book[37]. The use of equivalent units allows the sum of modes that use different fuels (e.g. electric trains and cars) and it is consistent with the units used in other sections of this research (e.g. heat load).

11.4.4.1 Metropolitan Travel Patterns Analysis

The spatial distribution of transport energy shows different patterns in London and Barcelona. In London, the strong specialization of the central districts as centers of employment contrasts with the residential character of suburban areas. Consequently, self-contention is very little in peripheral boroughs and the residents of those zones require longer commuting distances. Energy use increases constantly from the center towards the urban fringe, where residents require, as average, around three times more energy for personal travel.

In Barcelona, such radial increase is not so consistent. Variations across the metropolitan area are smaller than for London. However, the benefits from central residence are not reflected in travel patterns so clearly. Among central districts, only the Eixample presents a value in the lowest energy range. Other districts, such as Sant Martí, Sants or Sant Andreu are only in the medium range, the same as the satellite towns of Sabadell or Tarrasa and outperformed by some of the small villages beyond the first suburban ring. According to the data plotted in the map, commuting population seems to cluster in a first peripheral ring at a distance between 10 and 15 Km to the Old Port (Port Vell). Residents from those zones spend twice as much energy in travel as those from the Eixample. Beyond that ring, self-containment tends to increase due to the decentralization of industrial zones and the presence of important satellite towns, consequently transport energy decreases. A second ring of commuters appears around 30km from the Old Port, especially in the northern districts, which travel demand increases again.

11.4.4.2 Regional Travel Patterns Analysis

Since London and Barcelona are considered employment destinations of regional importance, their functional zones, which include their respective areas of influence, extend beyond their metropolitan area. A second set of maps was elaborated to analyze travel patterns and equivalent energy at regional scale. These maps could not be produced using the same datasets as for the metropolitan area due to the lack of consistent information for the whole region. This gap was resolved by applying regression analysis over a combination of variables from travel surveys and spatial attributes.

In London, the regression was based on the average distance to work of the residents of each ward and residential density. These were the two parameters that could predict energy in travel more accurately. Information about these two parameters was supplied at ward resolution for all UK by the Office of National Statistics[38].

Table.11-3 Statistics from regression analysis for London

Multiple correlation coefficient	0.98
Determination coefficient r²	0.97
Fitted r²	0.93
Standard error	807.99
Observations	31

	Coef.	Std Error	T-statistic	Prob
Density	-0.193	0.03284	-5.878	2.2267E-06
Distance to work	632.97	27.649	22.89	4.0947E-20

Similarly, in Barcelona the average time needed to reach the working place was the key variable to conduct regression analysis for the whole region[39]. This data was provided for Barcelona and Catalonia by the local and regional Institute of Statistics at municipal and district resolution[40]. A number of variables were tested to increase the predictive capacity of the correlation model. The two parameters that showed a stronger correlation were the average household income and the density of the place of residence. The correlation statistics are shown in table 11-4.

The regional maps confirm the trends identified at metropolitan scale. Centrality has a decisive importance to reduce travel costs in London, whose area of influence extends over a great part of the Southeast region. Satellite towns offer present a relative self-containment, whereas the residents of low dense suburban areas show a high dependence on long commuting journeys and motorized travel. Barcelona's functional zone extends up to 50 km away from the city center. Within this zone, variations in equivalent travel energy are non linear and less pronounced, around 30% between the zones with highest and lowest average values. The two suburban rings, at 15 and 30 km from the Old Port, are still highlighted by their relatively high equivalent energy. The towns along the Llobregat corridor are also identified by high motorized travel. The rest of the region shows a rather homogeneous distribution, with higher levels of self-containment and reduced energy usage in the hinterland respect to the outskirts of Barcelona metropolitan region.

37 Davis et al, 2011

38 Department of Neighboorhood Statistics Distance travelled to work. Dataset UV35. Density was available at the local profiles section: neighbourhood.statistics.gov.uk/ [last accessed 18.11.2013]

39 The level of aggregation was the municipality for Catalonia, except in Barcelona were data was broken down for the different districts

40 For Barcelona: Population mobility to work or to study http://www.bcn.cat/estadistica/angles/dades/guies/a2000/guia0100/mobi01/mobi01t1.htm [last accessed 18.11.2013]

For Catalonia: Travel time to work. Employed population over 16 years old. Distribution by municipalities. http://www.idescat.cat/territ/BasicTerr?TC=20&V0=1&V1=25001&V3=905&V4=749&ALLINFO=TRUE&PARENT=1&DISTRI=TRUE&CTX=B [last accessed 18.11.2013]

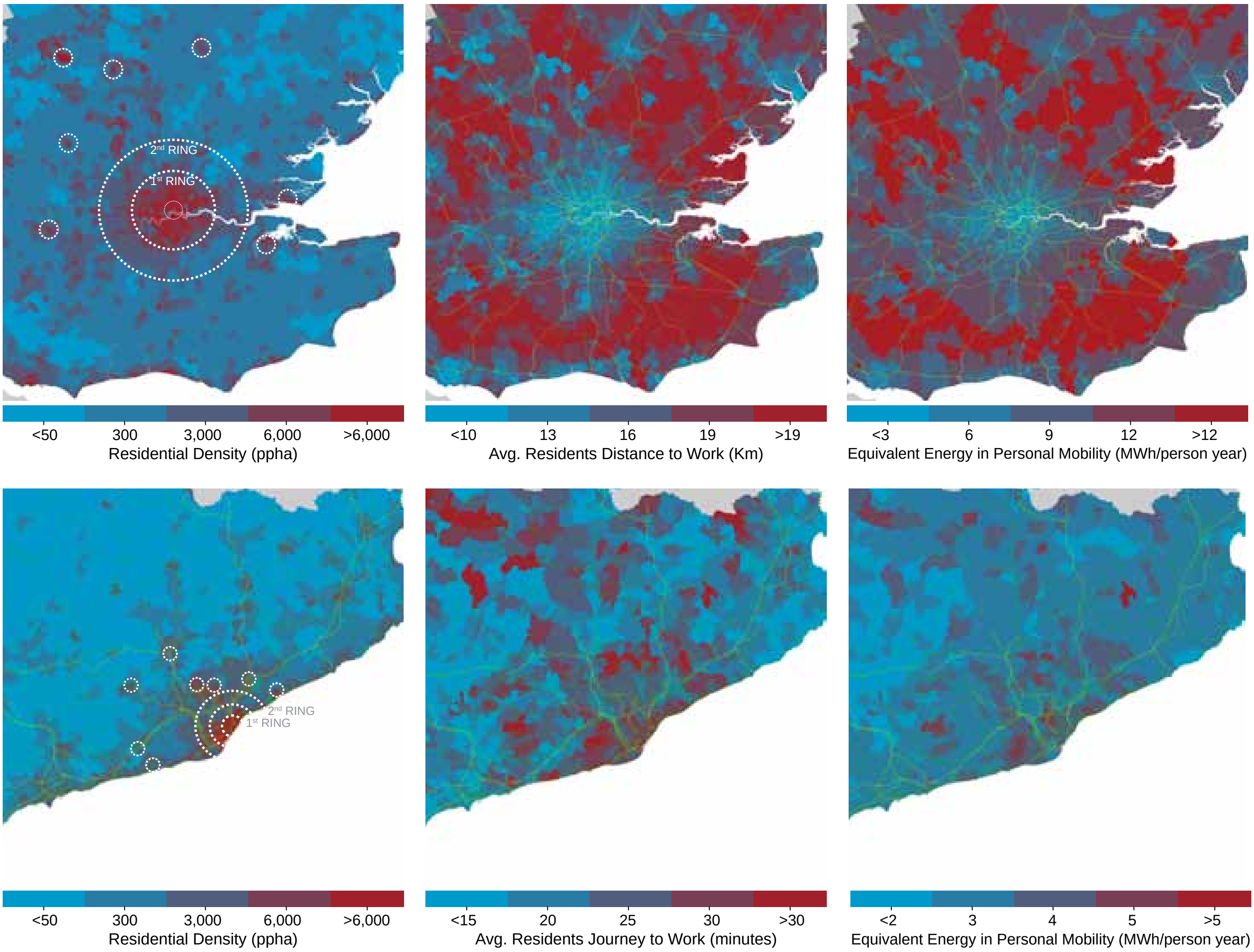


Fig.11-30 Regional travel patterns in the South East of England (Top) and Catalonia (Bottom)

0 40km

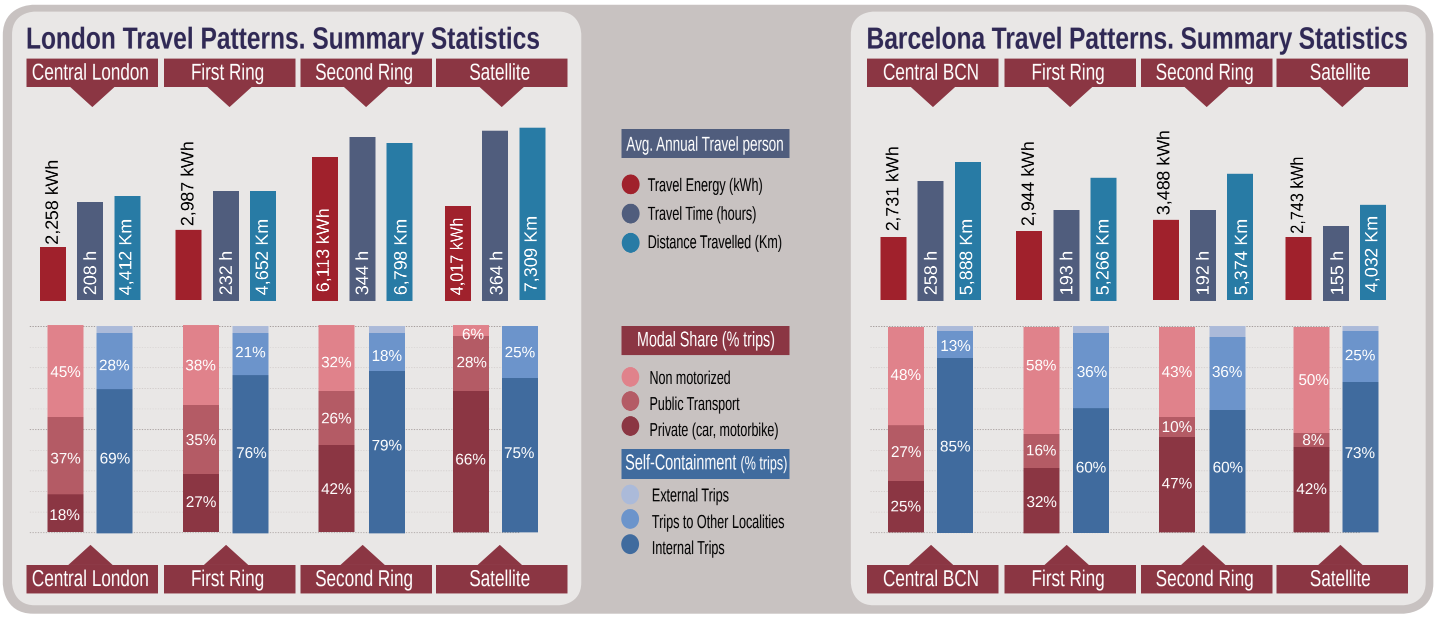


Fig.11-31 Current travel patterns in London and Barcelona. Summary Statistics

Table.11-4 Statistics from regression analysis for Barcelona

Multiple correlation coefficient	0.99
Determination coefficient r²	0.99
Fitted r²	0.91
Standard error	294.22
Observations	16

	Coef.	Std Error	T-statistic	Prob
Density	-0.0315	0.0167	-1.889	0.08140
Time to work	88.75	17.306	5.1281	0.00001
Gross Household income	0.0471	0.0156	3.00823	0.0133

Finally, the comparison between the average equivalent energy for travel purposes in Docklands and Poblenou respect to suburban locations denotes a potential for savings around 50% and 35% percent respectively. In both cases, fixing population in those central districts would potentially translate into a reduction of motorized travel.

11.5 The effect of compaction on travel patterns

The analysis of current travel patterns in the selected urban regions provides a sound evidence about the importance of the spatial arrangement of residential and working areas. The wealth of data allows, moreover, further explorations to speculate about the potential effects of urban transformations on transport energy and CO_2 emissions. Similar methods as those used for building's energy analysis were followed to evaluate different degrees of urban compaction or sprawl. The same base case and the same four alternative scenarios were used to test the travel costs associated to each of them. Therefore, the detailed explanation of scenarios is referred to that section and it will not be repeated here.

Hypothesis

The research hypothesis of this analysis refers to the magnitude of the benefits from urban compaction. The correlation between density and fuel usage has been taken as a dogma ever since Newman and Kenworthy report. Notwithstanding all the converging parameters that come into play, there is a general agreement that suburban low dense residential developments offer little incentive for public transport and non motorized travel. This has been confirmed, to a different degree in each region, by the previous analysis. However, the most controversial arguments on this debate refer to the magnitude of the possible energy savings. Past experiences have shown that a proportion of the expected benefits may not be met in practice due to feedback processes and side effects.

Methodology

The starting point is for this analysis was, both in London and Barcelona, the existing urban structure, which were defined by residential density, as it is the variable that can be most easily manipulated. Density maps were overlapped with transport efficiency, or the average equivalent energy (in kWh) spent in transport per person and year within each cell of the map (of resolution 100x100m). The result was a cartographic display of energy density, portraying the average transport energy per area unit (total kWh/hectare of land). The key statistics were extracted from this map, so that the average and total transport energy for the entire urban region could be found.

The same process was repeated for the two scenarios of urban sprawl (moderate and extreme) and urban compaction (moderate and extreme) for London and Barcelona. In the fictional scenarios, the average travel efficiency was recalculated, as the redistribution of density interacts with the original patterns, creating, new destinations and poles of attractions as some areas became denser. The correlations found in the initial analysis and compiled in tables 11-3 and 11-4 were used to account for these interactions.

Analysis

The results from the assessments of the base case and four scenarios are mapped in figure 11-32 and summarized in figure 11-33. As it can be noted, current travel patterns and spatial urban structure define different pictures in London and Barcelona. While the former reflects a significant sensitivity to variations in the urban form, the latter is barely affected by these extreme transformations. As shown by travel surveys, centrality exerts a decisive influence in the amount of travel of Londoners whereas in Barcelona, this connection was only consistent in specific districts, such as the Eixample. Consequently, the scenarios of moderate and extreme urban compaction in London offer prospective reductions in travel energy around 12% and 35% respectively. In contrast, further densification would hardly offer any potential decrease in the case of Barcelona, as the 2% reduction that is estimated in the case of extreme compaction, could be easily counterbalanced by external factors. This different performance could be explained by the fact that Barcelona is already a dense and compact city and that the yields from further densification are very little. However, the assessment of sprawling scenarios, for which there is a greater scope in this compact city, replicates the modest impacts, showing a mere 3% increase as result of extreme dispersion. This is even smaller than in London, where further suburbanization would potentially lead to an 8% increase in travel energy.

These results must, however, be taken with caution as they focus on the impact of urban form but they do not take into account the evolution of parameters that may induce an stronger distortion, such as unemployment levels, fuel price and average household income. Previous figures had shown how these factors were inducing sharp fluctuations that could be read in urban mobility indicators. In any case, useful connections between urban form and travel pattern

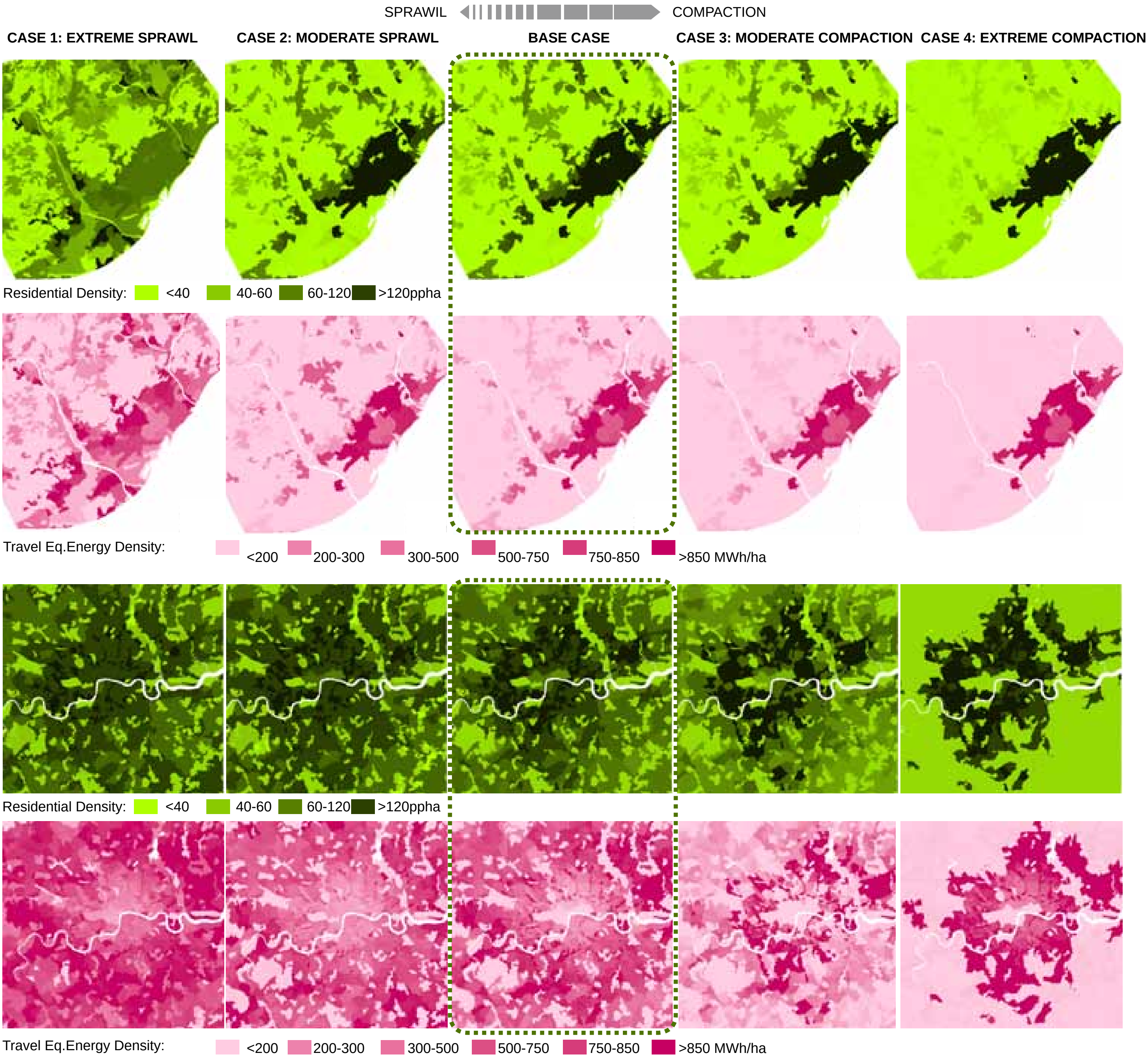


Fig.11-32 Urban Form and Energy Patterns. Base Case and Scenarios for Barcelona (top) and London (bottom)

can be extracted from this analysis. Centrality is stronger in London than in Barcelona. It means that commuters from the periphery are more numerous and take on larger journeys, which explains the greater potential associated with compaction. In Barcelona, the industrial decentralization has created a polycentric network, whose nodes are not restricted to the central districts but also include satellite villages, such as Tarrasa or Sabadell. Actually, a significant proportion of commuting flows could follow a reverse itinerary from the city centre to peripheral towns. The extrapolation of these insights to the case studies of Poblenou/22@ and Docklands suggest that the potential reduction in travel is greater in London, as counter sprawl measures offer larger returns. Moreover, in both cases, the regenerated areas have become neo-tertiary working nodes, thus attracting a flow of commuters from other parts of the region. Therefore although residents have lower travel needs, there has been a feedback in the system that has ensued in newer traffic flows from the outskirts to the regenerated areas.

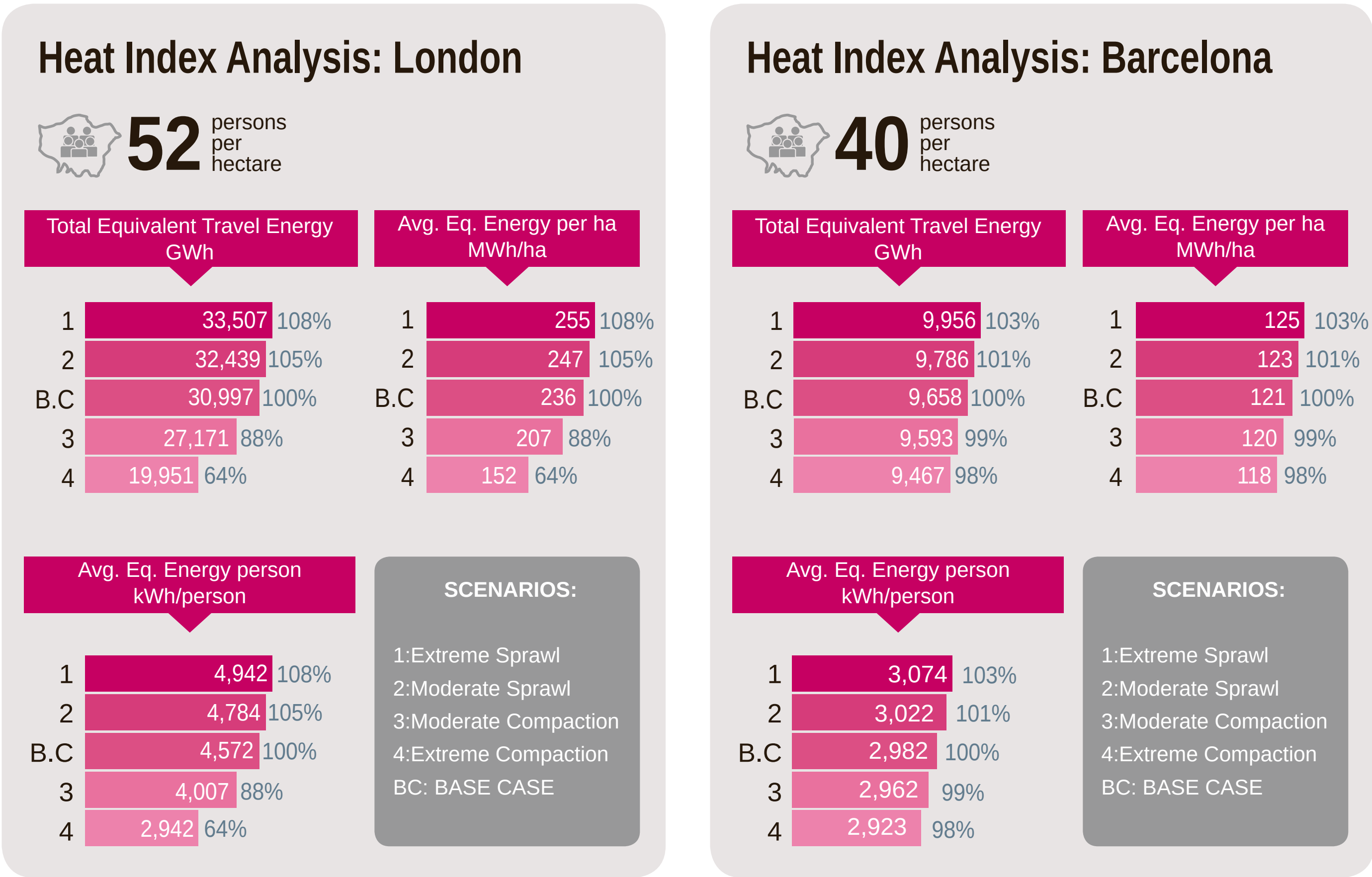


Fig.11-33 Summary statistics from travel energy analysis in London and Barcelona

11.5. Learning outcomes

A characteristic order arises through urban evolution. Morphogenetic analysis reveals prevailing urban typologies by the identification of the successive development stages of the city. Classic morphology theories used that knowledge to enhance the stylistic continuity between past and future architecture, preventing breaches such as those produced by modern planning. Nevertheless, urban typologies can be also defined by measurable attributes that contain information about aspects of performance, such as typical construction systems, architectural features or the prevailing urban geometry.

In this chapter, citywide energy performance analysis was initiated with the typological study of London and Barcelona. Seventeen samples were selected and calculated in the UEI tool. That first step sensed the performance range according to prevailing types. A second step focused on the study areas of Docklands and Poblenou, to observe the variations in the intensity of domestic heating demand induced by the regeneration processesm which could then be compared to alternative forms of urban growth. The results were inconclusive, as they were closely linked to the increment in residential density. A third analysis was conducted to assess the impact of urban transformations in transport and space heating at regional scale. Although in theory there could be limitless possibilities, the variations in urban form were linked to the existing structure. Four scenarios were created, two depicting compaction and two depicting sprawl. The regions were “pixelized” in cells of one hectare, whose evolution would be determined by the residential density in the base case. The average residential density of the regions was kept constant in order to prevent distortions; it only became more or less concentrated. The following observations were concluded by analysis of the scenarios:

- They confirmed the existence of connections between urban form and energy performance. Compaction led to a reduction in transport energy and space heating.
- The contribution by compactness is, however, modest in most scenarios. Even in those that portrayed radical transformations (except for transport and “extreme compaction” in London)
- The characteristics of the base case (the existing urban form) have an influence in the effectiveness of alternative scenarios, especially in travel patterns

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CHAPTER 12

CONCLUSIONS

12.1 Relevance

This thesis has tackled the difficult task of generating meaningful insights in the complex and thoroughly discussed subject of urban energy performance. Other approaches could have been less controversial and challenging. A commented compilation of findings from previous research, a rhetoric discourse based on accepted arguments or self-evident relationships could have been easier paths. This could have produced an unobjectionable document and a smooth navigation towards doctorate. Instead, a tortuous alternative was taken. The comfort zone of mainstream was abandoned to dig into the connections between urban form and performance, using unconventional approaches and applying original methods. It was presumed that if the enquiry was restrained within established theories and tools, it would lead to the same abstract conclusions that were to be tested in this thesis. Nonetheless, the research hypothesis was based on sound foundations, from which subsequent departures could be taken in order to bring forth significant and original pieces of analysis and thus advance in the consolidation of an urban science.

The pertinence of the research approach could be appraised by applying the four rules of scientific research as formulated by Umberto Eco[1] in his guidelines for the elaboration of a thesis:

a) The research addresses a well defined subject, which is known and acknowledged by others.

b) It provides original insights or it presents previous research under a different perspective.

c) It is useful to others.

d) It incorporates elements to verify or refute the research hypothesis. Other specialists, with enough knowledge in the field, could reach the same results.

a) The significance of the subject

The pertinence of studying the development of cities and the influence of form on urban performance can be easily justified. Cities are, as a result of the concentration of human activities, energy black holes. They consume resources, at a global scale, to sustain all the processes that take place inside their boundaries and then, they emanate wasteful residues to the surrounding environment. Since devolution towards a pre-industrial type of civilization is unrealistic in the medium term, the mitigation of the problems caused by the contemporary city is a problem that cannot be postponed. In the European context, the solution inevitably involves the consideration of existing cities. At a time when nearly 80% of the population of the continent live in cities, and after a century of continuous growth, neglecting the existing urban fabric would be misleading and futile. This research assumes the endurance of an urban society as an inherent condition of modern life and explores energy consumption patterns associated to the alternative ways in which cities may evolve.

b) The new perspective and original findings

The most relevant studies on this subject have been collected and listed in the initial chapters of the thesis (chapters 3,4 and 5). Their main findings were critically reviewed, tested and incorporated as theoretical background. Evidences of connections between urban form and environmental performance were consistently pointing to two antagonistic models: the compact and the dispersed city. The drawbacks and advantages of each type were exposed and balanced.

The prevailing line of thought considers urban compaction as a preferable option as it is alleged that its benefits outweighed its weaknesses. Some of the advantages of urban containment are rather evident and can be elaborated on simple inference. The enhancement of landscape preservation could be intuitively accepted as a direct consequence of the minimization of urban expansion as the pressure on rural areas is lessened. However, other factors, of greater complexity, have been often justified with simplistic arguments, taking causal relationships for granted and omitting the presentation of objective and contrasted evidences. Moreover, those studies that incorporated empirical data where either circumscribed to very specific cases, with little scope for extrapolation or, in contrast, failed to discern the key urban variables that were determining such performance.

This thesis has contributed to clarify some controversial aspects about the influence of urban form on city performance. It did not embarked on an all-encompassing appraisal but it focused on energy demand patterns. This was identified as a field that, apart from being of paramount importance for current and future generations, it urgently requires clear and

1 Eco, 2001

independent attention from an architectural and urban design perspective. This approach has allowed a balance between quantitative analysis and the contextualization of findings in relation with the processes behind the data. Potential patterns of energy demand derived from variations in the urban form were isolated from other factors, such as economic, social or behavioural. They were also subjected to empirical verification, provided by the study of twenty six urban regions and the case studies in London and Barcelona. These examples provided not only specific data but also a realistic framework.

The original findings in this dissertation are dispersed over the different chapters. The degree of novelty ranges from the reinterpretation and rationalization of existing datasets to the elaboration of new urban analytic tools to produce original estimates:

- In chapter 2, the typification of the metropolitan urban form was reformulated in relation to the spatial arrangement of quantitative parameters, as an alternative to classic definitions based on the analysis of visible phenomena. The percentage of people living in areas of a certain density replaced the ambiguous notion of density. Likewise, the percentage of land dedicated to economic activities that is located within walkable distance to the main residential areas aimed to provide an objective measure to the functional mixture of the urban fabric. These variables were then studied in relation with key urban performance indicators in order to unveil possible correlations. According to this analysis, those regions with higher ratio of urban population, living in denser and mixed districts tended to consume less energy but presented greater problems of pollution, noise and lack of green space. These findings could have been intuitively surmised, but in this case, are supported by evidences.
- Chapter 3 elaborates on the antecedents of the sustainable city concept to come up with an original theory to explain the evolution of urbanism in the last two centuries as successive periods of emergence and abeyance of collective environmental concern. It also portrays the main positions on the current discussion and the theoretical connections between urban form and sustainable performance.
- Chapter 4 starts as a review of previous literature on energy and urban form but it also contains original insights. Satellite data are analyzed, processed and presented to illustrate the effects and causes of the urban heat island (UHI). New findings about this phenomenon include the estimation of variations in energy performance due to the effect of the UHI. The correspondence between land surface temperature and spatial variables, such as density or land cover provide further insights. The last part of the chapter explains the variations of urban energy consumption per capita found in London boroughs as a consequence of their prevailing urban typologies.
- The main original contribution in chapter 5 consists on the compilation and appraisal of travel surveys. After explaining the principles on travel pattern analysis, eleven reports made on European cities were selected, compared and analyzed. A summary matrix portrays the most consistent connections between urban form and personal travel found in this analysis.
- Chapter 6 contains the most substantial part of the investigation. After a brief introduction on the precedents of urban and energy models, it presents an urban energy analysis tool that has been specifically developed for this research. The whole process of conception, validation and applicability is explained in full detail. During the development of the tool, especially during validation, a large number of urban samples were modelled and analyzed, thus producing a preliminary typological and parametric research about the influence of the urban context in the energy performance of buildings.
- Chapters 7 and 9 relate the historic evolution of London and Barcelona to the physical transformation of the urban fabric. This approach aims to understand contemporary cities as a result of social and political decisions taken at specific times. The prevailing typologies and the extent of urban boundaries in each period are identified and overlaid to the current fabric, portraying urban form at local and metropolitan scales. The evolution of the urban regions is reconstructed, emphasizing geographic features as determining factors of the urban form.
- Chapters 8 and 10 analyze the main regeneration projects that were undertaken in the inner districts of the selected cities, Docklands in London and Poblenou in Barcelona. These case studies exemplify the different consequences from massive regeneration projects and the conflicts that emerge when the area of intervention includes not only vacant land but also established communities. A great part of these two chapters is based on literature review and the exploration of a large number of sources, from old newspapers to pamphlets and reports. However, the processes have been also analyzed and quantified in a series of accompanying maps and images.
- The main findings of the research are synthesized in chapter 11, where the hypothesis and research questions are tested, using the case studies as base of the assessment. Almost all the material in this chapter is original or it has been re-elaborated (e.g. traffic flows diagrams and data). The chapter reviews and carries further analysis on the connections between urban form and energy performance of cities. The first part of the analysis addresses the local scale, this is, the urban fabric. The energy

performance of the typologies identified in chapters 7 and 9 is evaluated using the UEI application. The same UEI tool is then used to quantify the energy demand in the regenerated areas of Docklands and Poblenou, after and before the transormation. This gives an idea of the average consumption per capita in the renovated districts, which can be compared with the alternative scenario if thenew residents were living in suburban developments. The final part generalizes this comparison to assess alternative city forms. Four scenarios, two representing different degrees of compaction and two representing sprawl, were created and compared to the current city, which is used as base case. All the scenarios were simulated using the UEI to obtain the equivalent domestic heat load. A similar analysis was conducted to estimate the energy that would be potentially spent in personal travel under the same scenarios. The transport model was based on empirical data obtained from travel surveys in the regions of London and Barcelona. Only morphological variables were considered, leaving aside other factors. The findings from this chapter indicate that energy savings from compaction might be more modest than initially anticipated, especially in the case of Barcelona. The results suggest diminishing returns for increased compactness and density. Moreover, given the dimensions of the resulting values, other measures, particularly those based on architecture and urban design may have a much stronger an immediate impact than densification.

c) Research applicability

The research undertaken for this thesis has been both retrospective and prospective. It has looked into past events in order to gain a critical understanding of the contemporary city and the logic of the events that have shaped it. This knowledge can be applied to anticipate future trends, their likely consequences and to address potentially conflictive issues accordingly. In addition, it has proposed new instruments to analyze the energy performance of the urban form. It is expected that the UEI tool can be further developed in order to incorporate more precise definitions and a stand-alone interface. In this way, it could be accessible to urban managers, planners and designers who seek to integrate energy aspects from the preliminary stages of decision making. Its current configuration has been devised bearing in mind the state of the art in urban analysis, particularly the scope of geographic information datasets that urban agencies are able to provide at the moment. This information is highly variable for different cities and presents critical gaps that are expected to be solved in a near future. In Barcelona, cartographic datasets with information of building's footprint and volume are freely available, have little restrictions, and are highly consistent. In London, the Ordinance Survey is the main provider and it offers free cartographic datasets. However, they lack information on building height and this has to be obtained from alternative sources, with greater restrictions and numerous gaps in the spatial data. At the moment, important parameters of the building fabric, such as completion date, use or materials are either inexistent or have to be collected through time consuming efforts. However, it can be assumed that consistent spatial datasets will become gradually available for most European cities, with standard configuration that should include these key performance variables. The UEI could then be easily adapted to make more accurate predictions, computing the specific data of each building, instead of using typical values as it currently does. As real energy consumption could be also gathered from service providers, discrepancies between expected and real demand could be identified, thus allowing further calibration of the tool. It could then become a common aid to manage energy strategies at urban scale. Potential applications include:

- Identification of the areas of the city whose morphology induces higher energy demand. Retrofitting policies could prioritize the zones or urban typologies which are more vulnerable or have greater returns.
- In addition, the tool performs quick estimations on the effects of specific measures, such as window replacement or increased insulation, in large areas of the city. The value of existing insulation or construction materials can be inferred by the estimated period of construction until more complete information is gathered for the whole city.
- Assessment of behavioral changes. Some cities are considering the need for specialized offices, to provide advice to their residents about how to reduce their energy bill by soft measures and behavioral changes. Adaptive strategies can be introduced in the UEI. The area of influence of that local advisory office could be estimated and the potential energy savings could be derived as the combination of urban morphology, building construction and behavioural patterns that can be inputs in the UEI.
- The potential energy demand associated to a development plan could be estimated, even from strategic plans (city wide and regional plans). Despite the abstract definition of urban planning, comparative estimates could be obtained from their statutory prescriptions regarding plot coverage and built up area.
- In detailed urban projects, in which buildings are defined to a greater extent, it would be possible to perform quick estimates at early design stages. Aspects such as compactness, orientation and window to wall ratio could be investigated and optimized by iterative assessments. Since the tool provides average estimates for the whole scheme, the range of performance of the different building units would be synthesized in one value, which

leaves greater flexibility for the urban layout. Urban projects that prioritize "green" performance tend to be overly deterministic, leading to convoluted geometries seeking for the "optimum" orientation and minimum obstruction. The conceptual definition of the UEI tool emphasizes the overall performance of the urban area over the individual buildings. In this way, a relatively poor performance of some units can be balanced in the average value.

d) Replicability

All the procedures and methodologies followed in this thesis have been explained in detail. Complementary data is provided throughout the document to support the explanations with objective evidences that illustrate every step. Even in those cases where results were not totally satisfactory, they were not omitted. At contrary, weaker or inconsistent results have been transparently pointed out as clarification of the research's position and scope.

Anyone with the interest, the time, the skills and the logistics could replicate the analytic work and get to similar results. All the information to undertake such task is included in chapters 6 and 11, while further details can be found in appendix I.

12.2 Hypothesis verification

This thesis started from a research question that can be formulated in conventional and general terms as follows:

"Is the compact city the most sustainable urban form for current and future cities?"

However, this initial hypothesis encompassed a wide range of issues that derived in a series of specific research questions. Subsequent research was structured according to these questions, aiming to reduce the number of uncertainties and to challenge vague formulations that often accompany the answers to the main research hypothesis.

- **Regarding Urban Processes and Form:**

What defines a compact city? What benefits does it offer?

The compact city emerged as the antagonist of megalopolis and urban sprawl that came after industrialization and the generalization of car ownership. Although a precise definition has been never agreed, it implies a notion of containment, a dense urban fabric within well defined boundaries. Descriptions of the compact city allude to characteristic medieval structures or Mediterranean towns, a celebration of the street as centre of social interaction, collective housing as efficient use of land and the combination of activities as enabler of prosperity. It also implies a negation of post-war planning, based on modernist principles, open blocks, decentralization and zoning, which gave rise to characterless suburban areas, ghettos and the dismantlement of historic quarters in favour of road traffic access. Barcelona has been commonly portrayed as the paradigm of the compact city ideal. It combines high density in the central districts, intertwining of living and working areas and the relative containment of suburbia. The international recognition that the city obtained in the 1990s reinforced the appeal to compactness and density as means to improve urban quality and made it desirable target to other cities. London was among those cities that took the Barcelona model onboard to reverse the ongoing suburbanization forces that had generated endless rows of low density terraces, spread over a ring of over 50 km diameter.

However, London, as Barcelona, has certain areas than fall under the compact city concept. Camden, Islington or South Kensington combine moderate residential density with a varied concentration of retail, service and creative jobs. Conversely, Barcelona has produced suburban forms of urban growth in the last decades. Therefore, the notion of compactness, as traditionally understood, is a relative term, applicable to specific areas, but too ambiguous when referred to the metropolitan scale. It is inaccurate to characterize an entire urban system (the urban region) with a concept that implies attributes that occur at local scale. Urban life is as thriving and exciting in Barcelona's Eixample as in Bloomsbury, although the cities that contain these districts have been described as antithetic urban forms.

Urban regions do reflect containment when, either the proportion of urbanized territory is relatively low, or the population is concentrated in areas of moderately high density. Likewise, they present evidences of functional mixture when tertiary and industrial activities are integrated with those dense residential zones. It is possible to establish quantitative definitions, under these criteria, to describe the relative compactness of urban regions. When a selection of European regions was analyzed in these terms, the results confirmed some of the intuitions regarding the differences between Mediterranean and north European areas. Madrid, Barcelona or Lisbon are consistently among the regions with higher degree of demographic concentration and greater mixture of uses, while Birmingham or Cologne represent the opposite pole, with dispersed population and a sharp separation between residence and working areas.

What other urban forms can be found in the contemporary city? How can they be defined?

Following the previous analysis, it was clear that a static classification of the urban form was meaningless. Urban systems are dynamic structures and they have to be defined accordingly. Cities and civilizations have alternated periods of growth and declined during history. However, the industrial revolution engendered a long cycle of continuous growth that accelerated urban expansion dramatically. The political and geographic context determined the response of cities to demographic pressures. Some of them could colonize the territory rather freely, whereas in other cases geographic barriers or the inability to provide adequate transport determined concentrated forms of urban growth. In the last few years, the expansion of European cities has decreased, and even the idea of shrinkage has recurrently come up. Two centuries of continuous growth have shaped three consistent types of urban systems in Europe, defined by the concurrence of urban nodes and their hierarchy:

- Monocentric, if only one prevailing centre can be identified
- Polycentric if there is more than one centre with a hierarchical structure
- Networked urban systems, which are composed of complementary nodes without a clear hierarchy.

These are the main types defined by the consolidated urban fabric. They are complemented with the prevailing forms of current urban growth in the metropolitan region. Essentially, the expansion of cities in the last decade can be summarized in two types: concentrated growth, in clearly delimited areas or, dispersed growth, creating a diffuse form of suburbanization. Although other classifications are possible, the combination of these two notions, spatial structure and expansion, creates synthetic categories that portray the essential character of contemporary European cities.

Why are urban form classifications relevant? Is there any connection between urban form and other spheres of urban activity?

The study of urban form has a double intention. On the one hand, it helps to understand the current structure as a physical residue of historic episodes of urban evolution. The morphological classification of urban systems aims, therefore, to extract the connections between those processes and the spatial configuration of the city. On the other hand, it has been assumed that the form of a city determines its performance in a number of aspects. Even the first designed cities applied models and solutions based on merely functional grounds. The Greeks limited the size of their cities to allow citizen participation in their general assemblies while Renaissance ideal villages were designed to maximize defensive capacity. The identification of formal patterns intends, in this case, to explain the links between urban structure and processes. It is a phenomenological approach to derive theories on urban performance.

The connection between form and performance is not an original formulation but an intrinsic attribute of urban design. The main difference lays in the high complexity and the number of factors involved in the contemporary city. Basic needs (food, water provision, defence or governance) can be now fulfilled regardless of the size, location and shape. New expectations have come forth in contemporary urban societies. The nature of cities as centres of economic activities (not in vain they emerged from the marketplace) has been reinforced. Great attention is paid to issues such as employment, investment or tourism. In a next level, citizens also demand good places where to live and work, with high environmental standards, signified as access to nature, accessibility or air quality, among other aspects. The observation of key dimensions of performance in relation with morphological variables suggests a capacity of the urban fabric to influence a broad range of processes, in particular environmental systems. The phenomenological approach to urban form opens multiple lines of research on these fields.

- **Regarding Sustainable Development and Urban Metabolism:**

What is a sustainable city? Which are the performance dimensions that characterize it?

The sustainable city concept has been contentious. The use of term itself is often seen with suspicion and disbelief due to its recurrent use. However, a lengthy semantic discussion has no interest for this thesis. It is considered as an appropriate term as any other and it presents the great advantage of its universal meaning. Although there might be different connotations, it can be understood by a wide spectrum of population, across cultures, nations and disciplines. The official definition of sustainable development was formulated in 1987 by the Brundtland Commission as the balanced exploitation of resources to ensure welfare for current and future generations. However its translation to urban disciplines admits interpretation and requires further precision.

The sustainable city is an ideal abstraction that sets the current framework criteria to evaluate urban performance. It is not bound to or limited by statutory resolutions, although it has been defined repeated times under diverse perspectives. There is a consensus, however, on certain aspects that should be prioritized to attain more sustainable cities:

It points towards a balance between environmental, social and economic factors. Unlike previous environmental waves, this approach is neither specifically concerned with natural preservation (like the ecological movements of the seventies) nor with the living conditions of the population (like the garden city or the hygienist movements) or the economic reactivation of decaying areas (like the urban renewal of the eighties). A sustainable city cares equally for all these elements while embracing a metabolic approach to account for resource consumption. However, in the light of recent events, the general objectives of sustainable development should be reviewed or renamed as environmental, social and ethical sustainability.

Those three main categories can be broken down into more specific elements, to set the priorities of contemporary cities.

Among these factors, the reduction of energy consumption emerges as one of the main challenges, followed by mobility and transportation, water and waste management, social equity, identity and sense of place, innovation or technological development.

The sustainable performance of cities refers to the degree of achievement in each of these categories and the balance among them. Although the resource perspective has become a predominant argument in the last years, cities are complex systems whose harmony depends on both material and immaterial processes.

Which are the main advantages of urban compaction in the sustainable framework?

In the last decades, the case for the compact city as sustainable urban form has raised a broad consensus. The main arguments to support this claim were based on the potential reduction in the need for travel, the preservation of greenfield land and the enhancement of urban life. It was defended that external impacts and CO_2 emissions could be reduced by means of concentration. Critics would argue that potential benefits were not fully proved and, in most cases, they might be only achieved at a high cost, in terms of the social strain, congestion and pollution that are derived from densification.

This thesis explored the effects of compaction from two complementary points of view. On the one hand, a metabolic approach was followed to assess the potential connections between urban form and energy demand. On the other hand, specific case studies were analyzed to understand the broader aspects involved in operations of urban densification. The investigation of empirical data unveiled substantial variations in the energy performance of buildings and transport within metropolitan regions. The spatial distribution of those variations revealed that peripheral districts tended to present higher levels of energy demand for domestic and personal travel. These data corroborated the hypothesis of urban containment as a measure to efficient urban metabolism.

How are energy patterns related to urban form?

The empirical observations described in the previous paragraph were taken with caution as it was understood that other factors than the spatial form were acting upon these patterns. For instance, the residents of the most peripheral districts were, in general, wealthier than those of central areas. They could afford longer commuting journeys, larger homes and a more intensive use of the private car or heating systems. One of the objectives of the thesis was to make a clear distinction between the effects that can be attributed to urban form and other factors. The structure of those cities was modelled at different scales to assess the variations in energy performance when all factors but morphological were kept constant. The results from the assessment supported the theory of greater energy efficiency as result of urban compactness, with some connotations:

- At local scale (fabric), dense and compact urban typologies can result in up to four times less energy spent in heating (which is about half the total energy consumed in residential buildings) than suburban types. This is, however, an extreme value. Twofold variations were observed in Barcelona, while lower fluctuations were found in London.
- At metropolitan scale (the city in the region) differences up to 30% in domestic heat load can then be explained by the variations in urban form. The scenarios that depicted compactness were up to 18% more efficient than the base case.When urban sprawl was enhanced, the heating load increased up to 20%.
- Regarding travel pattern analysis, the equivalent energy consumption per capita increases, in general, as we move away from the central districts, except in satellite towns, which have a lower dependence to the central city and, consequently, a lower proportion of commuters.
- Urban form has an influence on travel patterns and equivalent energy consumption. Urban compactness favours the use of public transport, non motorised modes and self-containment. However, the extent of energy savings due to variations in urban form presents substantial differences for each case study. In London, the radial network has defined a concentric structure. Outer districts are invariably associated to higher travel. In contrast, those patterns are less pronounced in Barcelona, where the hilly topography has set boundaries to sprawl, while the decentralization of economic activities augmented the number of suburban trips (from one suburb to another). As a result, the equivalent energy for travel in London is more sensitive to the urban form than in Barcelona. Variations up to 35% percent could be potentially achieved as consequence of morphological transformations in the former, whereas smaller fluctuations, around 5% were found in the latter.

- **Regarding Morphological Transformations**

What does compaction or densification processes involve? Which are the social implications?

Which planning instruments are available?

The results from simulations must be relativized as they are only useful if they are interpreted context of urban logic.

Urban compaction requires a long term strategy over a large extension of the existing city. The resistance to change of the consolidated urban fabric is determined by different factors: the degree of occupation and urban intensity, the structure of land property, the presence of communities or economic activities are factors that may prevent substantial changes to be achieved. The two case studies that were analyzed in this thesis represent two major operations that transformed 2,000ha in London and 500ha in Barcelona. Their implementation required over 30 years and caused a severe social strain. However, they only accounted for less than 5% of the extension of each city. This is a small proportion and it meant that, eventually, the impact on the overall urban metabolism was little.

The current trend of urban growth in Europe is towards decentralization. Cities present little resistance to suburban expansion compared to infill development. The observation of urbanization patterns in London (fig. 8-54) and Barcelona (fig.10-46) reveals an average urban growth around 500 ha per year during the last seventy. Four times the extension of the Poblenou and Docklands were being urbanized in each respective city during the same period these projects were being carried out. It can be said that the two cases led to a deceleration of suburbanization rate but not to its reversal.

The scenarios created to assess citywide energy performance were assuming fairly large morphological transformations in order to unveil significant patterns. According to the trends described in the previous paragraph, only the moderate sprawl scenario could be considered a realistic scenario, whereas the other three are merely speculative. This means that, although extreme compaction could deliver energy savings, it would require traumatic measures for the city.

It can be argued that other measures offer greater opportunities to reduce the energy consumption in cities at a lower cost. Previous research demonstrated that environmental retrofit has a large potential to reduce the demand from existing buildings[2]. Regarding travel, the congestion charge proved an immediate reduction on the use of private cars in central London. The promotion of cycling was less controversial but likewise effective in changing travel patterns in those cities that designated lanes and incorporated cycling facilities.

It can be concluded that, in a period of demographic contraction, sequential urbanization should be an absolute requirement. Infill regeneration should be prioritized to any further expansion. Interstitial spaces should be programmed and developed. Urban design becomes of paramount importance to create spaces of great urban quality that enthuse new and existing residents while discouraging migration to suburban locations. The mitigation of pollution, the ingenious integration of green areas and design solutions to privacy and acoustic issues will be critical variables in the design of infill schemes.

12.3 Conclusions regarding methodology

12.3.1 Energy predictions: pertinence and usefulness

Studies on urban metabolism have to face the dilemma of sticking within purely theoretical terms or trying to provide estimates and predictions of likely patterns based on evidence and calculations. Rational deductions are useful to elaborate succinct descriptions of partial facts but they offer a poor capacity for exploration and speculation as they produce weak predictions when dealing with complex realities. Statements such as “density and mixed use lead to a reduction of distance between activities, therefore it leads to a reduction of travel, hence leads to energy efficiency...” are reductionist simplifications that may conduce to wrong conclusions as they are purposely ambiguous and casuistic.

In contrast, predictions based on numerical or physical relations face continuous scrutiny as long as they are transparent and open to examination. Mathematical formulations can be analyzed as for mistakes or procedural flaws. Even if the expressions and relations were correct they may be insufficient to reflect all intervening variables. Moreover, even models that achieve the greatest disciplinary approval can be refuted by reality checks when the expected outcomes are not delivered. Classic examples can be found in economic sciences. Novel algorithms to predict the market’s behaviour were put forward, reviewed and recognized by the scientific community but failed to predict the biggest downturn in the current generation. It does not mean that prediction models have to be dismissed, it just emphasizes that they should be taken as complementary instruments, requiring of the broader context for their precise interpretation. It has to be understood that a dynamic system will not always respond in the same direction to the same external stimulus. This can be explained by feedback reactions, adaptation or stochastic processes. For example, remote workers, working from home, may have a greater desire to travel in their leisure time, which may increase as a result of reduced commuting.

Both approaches, creative reasoning and objective computation, need to be knitted together, in order to produce sound research and generate knowledge. A new theory results from a combination of speculative assumptions and contrasted facts, which are tested and, eventually, validated. The omission of a theory gives rise to the erratic collection of facts that lack contextual information and can be hardly extrapolated. The disregard for the facts is only conceivable in populist and complacent discourses, and they will not stand serious examination.

The presentation of energy predictions, with specific figures, has been a conscious choice in this thesis, accepting scrutiny and critical assessment. The values were obtained from contrasted data and reliable sources, as well as from models and assumptions that were sufficiently explained as to emulate the whole process. It was considered that, although results could be challenged, a proposition on explicit terms would be more valuable to the field than a conservative formulation based only on known facts.

2 Rodríguez Álvarez, 2008

12.3.2 Development and application of an urban model

An important barrier that was found in this research was the weak penetration of cutting edge analytic instruments in the fields of architecture and urban design. Other disciplines, such as geography, sociology or environmental engineering seem to have taken a lead in terms of territorial and urban analysis. These areas have taken advantage of GIS potential to develop methods that are specific to their fields, but also to stretch their competence and credibility on planning and design decisions. Architectural training combines humanist and technical contents in a similar proportion, which provides a great potential to generate unique research. However, many of the tools that are being developed for urban analysis have aped other disciplines, borrowing conceptions and imitating procedures in an uncritical way. The way in which analytic instruments, such as the urban network analysis (tested in chapters 8 and 10) or complexity indexes, can inform design is still unclear and may force improper determinism on urbanism and architecture. On the other hand, those tools that combine analytic capacity and design potential, such as Ecotect or Open Studio, have been conceived at building scale and cannot be applied for large urban areas.

As the available tools were considered unfit for the research approach of this thesis, alternatives had to be created ad hoc. Eventually, a considerable amount of work was dedicated to the development of an urban energy analysis tool. It became, in fact, one of the most important pieces of the research but it allowed subsequent analysis and opened new lines during its elaboration and testing. For example, the validation process was, at the same time, a typological analysis, which was carried forward in the investigation. Although the tool was created to meet the particular needs of this research, it is expected that a future development will allow its application in urban planning and design projects. As it has been mentioned several times, the aim was not to create absolute predictions but to assess likely trends associated to urban parameters that are commonly used in planning. Its quick response and ease of use will enhance its integration as analytic and design tool. Retrospectively, the investment of time and effort required by this task is worthwhile as it greatly expanded the research potential.

12.3.3 From empiric to theory and vice versa

The theoretical and analytic enquiry was contextualized with two case studies in London Docklands and Barcelona Poblenou. It was a fundamental methodological decision that the research should not be confined to the realm of virtual abstraction. Those issues that could be observed in reality should not be investigated from a merely theoretical point of view. The analysis of real processes was not only insightful but also a reference filter that helped to discern between plausible and feasible. The critical understanding of reality informed the orientation and scope of the research hypothesis and placed further connotations upon findings.

More specifically, London and Barcelona embodied sprawl and compactness respectively, as they have often been referred as paradigms of these opposing concepts. The chronicle of their urban evolution illustrated their gradual and slow expansion over centuries, alternated with long periods of physical and demographic stagnation. Those processes followed similar patterns until the industrial revolution, which fuelled the first explosion and shaped different realities in the two cities. The urbanization pace in the last century was unprecedented. London spilt like a fluid on a flat table while Barcelona was constrained by the sea and the mountains but also by immaterial forces, that forced it grow denser. The present situation responds, therefore, to a complex evolution that has to be acknowledged in order to understand it and to elaborate meaningful proposals.

In both cases, large operations of urban renewal have been undertaken in the last three decades. Docklands and Poblenou have been interpreted here as processes of urban densification, as they were opposite to prevailing suburbanization trends. Their selection as case studies was based on the hypothesis that urban compaction would have different effects on different urban contexts. In general terms, Docklands was an example of densification in a scattered city whereas the Poblenou was an example of densification in an already dense and compact city. The expected environmental consequences and affections should, therefore, be weighted accordingly. The initial hypothesis was confirmed after the analysis, as potential benefits in energy consumption were lower in Barcelona.

It is clear that the case studies were not chosen for their intrinsic sustainable attributes. Except for some claims made at the 22@ plan in Barcelona, they had neither intended to become, nor had they been showcased as models of sustainable development. It was an explicit methodological decision to select only projects that had been never considered from an environmental point of view. Examples of sustainable urban projects are numerous and can be found in a wide number of publications.[3] However, they typically represent exceptions or singular projects with very specific conditions. Notwithstanding all the interesting discussions and the strong controversy that may arise from examples such as Masdar, Dongtan or Bed-Zed, their outcomes can be hardly applied elsewhere. They are, simply, too special. When the regeneration at Docklands and Poblenou were started, around 1981, the main concerns in urban planning were social and economic. The obsolescence of the central industrial zones was an evident problem that had little to do with a sustainable agenda that, on the other hand, had not been defined yet. These projects involved, nevertheless, a great diversity of issues, many of which have been recurrent in the last

3 Joss, 2010

decades. A broad range of planning instruments, involvement of local communities, incentives for developers, reactivation of derelict areas, gentrification and densification, are among the processes that can be analyzed in these case studies. They reflect planning trends better than a showcase project and, for this reason, offer greater learning opportunities.

12.4. Future research

This thesis aims to be a seminal work to be continued by the author and others in some of the research lines that it put forward. Possible lines of investigation include further analysis on interstitial urban transformations, reclamation of brownfield and industrial sites, urban energy efficiency or the impact of new economic models in the urban fabric. The advance of new theories on urban morphology and the exploration of its influence on performance still require further attention. The exploration of urban typologies that combine moderate density, compactness with solar access and green areas is an interesting design exercise that can involve the use of new instruments and the revision of built examples. However, the main priorities to keep up with the investigation in the short term would focus on:

- **Development of the Urban Energy Index** analysis tool so as to calibrate other climates and building types.

- The full integration of the tool in GIS systems and the creation of an stand-alone version with its own interface, so that it becomes available to an wider audience.

- **The adaptation of the tool to specific purposes, such as urban governance, design or planning proposals** that may require ad hoc functionality. One of the expected applications of the tool will be the elaboration of predictions to optimize public resources. For instance, the estimation of returns from subsidies to incentivize building retrofit in an urban district. The impact of this policy could be calculated beforehand, to select the areas of the city that can deliver the greatest savings or the specific measures that will be more effective in that particular zone according to its urban typology.

- **The extrapolation of the analytic methodology to other locations**, in order to assess alternative planning scenarios in specific contexts, particularly in Galicia, in the northwest of Spain. Although the European built environment is characterized by the strong polarization of the urban regions, with a concentration of wealth and power around larger capitals, the study of intermediate cities will be essential to fulfil the foundational goals of the European Union, regarding cohesion and social balance among regions. The areas with the greatest potential to produce energy efficient communities and appealing environments are located in southern latitudes, in the so called peripheral estates (Spain, Portugal, Italy, Greece...). The current economic logic explains an ongoing migration from southern to northern Europe, this is, from milder to colder climates. In a period of soaring fuel prices and decreasing dependence on centrality, we may be reaching a point where the energy costs may determine companies and people to decide their location based on aspect such as the mildness of the climate or their running costs. This has been already suggested by Edward Glaeser[4], who, half jokingly, implied that colder industrial cities of the rustbelt should be left on their own devices to encourage migration to California, with a milder climate. In the European context, it can be easily proved that southern regions, like Galicia, provide better conditions to achieve nearly zero energy buildings and cities than Germany, Belgium or United Kingdom.

- The integration of energy prescriptions in building and planning regulations. This is a controversial issue that has been clumsily addressed by planning laws as there is a lack of coordination between urban and building scales. While minimum thermal conditions have been enforced for buildings' elements, a great extent of their energy performance will be determined at the urban scale, for which no directions were given so far. This line of research would analyze alternative planning instruments to increase the capacity to influence the energy efficiency of future developments and regeneration projects. FSI and GSI or equivalent indicators are commonplace in current planning practice, if they were complemented with Compactness Ratio, a reference performance range could be estimated without compromising the flexibility of architectural design, which is essential to produce high quality urban environments.

- **Urban pollution** is a major issue that needs to be integrated in planning. This thesis has focused on metabolic aspects of urban form, but future work should incorporate the mitigation of pollution as, perhaps, the most important performance indicator for urban life. Precedents like Hong Kong, where wind corridors have been protected to mitigate to the high pollution levels, should be a warning for cities that combine high density and compactness.

- Smart City plans : Integration and development. The Smart City involves a combination "of ICT with traditional infrastructures, coordinated and integrated using new digital technologies"[5]. Its goals include the development of models and methods for "using urban data across spatial and temporal scales"[6] and "defining problems relating to cities, transport and energy"[7]. Smart city plans are being undertaken in many European capitals. Although this notion has been pictured as massively wired streets, in practice it has more to do with the integration of digital technologies in urban management. The use of analytic instruments, such as the UEI, to assess energy performance will be essential to meet the targets of the smart city.

4 Glaeser, 2010
5 Batty et al, 2012
6 Ibid
7 Ibid

Final plight: the future cities have been already built

During the next decades, the main challenges of European urban planning will reside within the boundaries of existing cities. The model of continuous growth, driven by industrialization, which characterized the last century is nearly exhausted. The current extension of most cities should be able to accommodate the urban population predicted by demographic forecasts. However, these cities have been built for other times, other needs and other expectations and they need to be adapted to their future residents.

The urban fabric of cities can be classified according to their resistance to change and adaptation. The structure of land property, its density and functional condition define the potential to transform an area. Large industrial estates, with few landowners and obsolete structures present, in principle, the greatest opportunities to introduce new and efficient typologies at the core of the city. In contrast, dense residential districts, with their land property subdivided in vertical layers, can be only transformed at a great cost.

If the compact city model succeeds and no significant suburbanization is to be undertaken, the old industrial districts will be subject of massive transformations. They will follow the examples of Docklands and Poblenou, but also of Liverpool, Manchester, Genoa, Rotterdam, Lille, or Milan. New interventions can learn from these precedents to overcome the issues that affected them and be able to create balanced communities in efficient high quality developments. But they may also bring about an unforeseen response, especially when the most resistant parts of the city become in evident disrepair. The dual city problem can be exacerbated if regeneration projects are limited to areas where intervention is easier and simpler. Modern, technological districts with wide green areas can become gentrified oasis for the wealthy urbanites while other parts of the city are lacking the same kind of urban quality because they were bound to an outdated structure.

Environmental retrofit can partly improve living conditions inside the dwellings of dense neighbourhoods, but the attainment of urban quality may require further ingenuity and more audacious solutions. The future debate on sustainable urban form involves decisions on what parts of the city deserve to be preserved and the extent to which the other parts can be transformed. New instruments should be put in place to gain the complicity of local communities and avoid traumatic interventions. The integration of new technologies in urban management can enhance the optimisation of resources. Open data and shared information will contribute to extend the knowledge of every city’s performance. Only with sound information, it would be possible to conceive city models leading to efficient and fulfilling urban life.

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APPENDIX I:
DATA SPECIFICATIONS

APPENDIX I: DATA SPECIFICATIONS

This appendix contains complementary information about methodology, data specifications and calculation procedures. It has been organized by chapters.

Chapter 2: the Study of Urban Morphology

Fig. 2-20 Urban Regions: Land Cover

These maps are composed of layers from different sources. They were processed and plotted in GvSIG v.1.11

1- Digital Terrain Model obtained from Global Multi-resolution Terrain Elevation dataset 2010 (GMTED 2010). The dataset was developed by the U.S. Geological Survey (USGS) and the National Geospatial-Intelligence Agency (NGA). Available at

- http://topotools.cr.usgs.gov/GMTED_viewer/viewer.htm [last accessed 20.12.2013]

The GMTED raster tiles were re-projected to an UTM coordinate system and applied a color table and shaded relief using Sextante toolbox. Transparency and further adjustments were implemented to portray a realistic effect of the terrain

2- Urban layers were obtained from Corine Land Cover datasets 2000 and 2006 (some data for UK was missing in the 2006 dataset). Data was processed and plotted in GvSGI v.1.11. Original layers are available from the European Environmental Agency:

- http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database-4 [last accessed 20.12.2013]
- http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version [last accessed 20.12.2013]

Fig. 2-21 Urban Regions: Residential density

Raster data on population density using Corine Land Cover 2000 inventory

Data are available at 100 meters resolution.
Population by commune correspond to Census 2001 (Eurostat). Processed and plotted in GvSIG v.1.11

- http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2 [last accessed 20.12.2013]

Fig. 2-22 Urban Structures

Base layers from: The Urban Atlas

“The Urban Atlas is providing pan-European comparable land use and land cover data for Large Urban Zones with more than 100.000 inhabitants as defined by the Urban Audit. The GIS data can be downloaded together with a map for each urban area covered and a report with the metadata”

- http://www.eea.europa.eu/data-and-maps/data/urban-atlas [last accessed 20.12.2013]

Fig. 2-23 European Cities. Comparative Data

The key performance indicators were obtained from the following sources:

- Kennedy, C.A., Ramaswami, A. Carney, S. & Dhakal, S. (2011) Greenhouse Gas Emission Baselines for Global Cities and Metropolitan Regions. In Hoornweg, D. Freire, M. Lee, M.J. Bhada-Tata, P. & Yuen, B. eds (2011) Cities and Climate Change: Responding to an Urgent Agenda. The World Bank
- EEA (2009) Ensuring Quality of Life in Europe’s Cities and Towns. Tackling the Environmental Challenges Driven by European and Global Change. European Environment Agency

- Gallup-Hungary (2010) “Survey on perceptions of quality of life in 75 European cities” European Commission. Directorate-General Regional Policy
- Urban Audit (2004) City Profiles. Eurostat and European Commission Directorate-General Regional Policy. Online resource: www.urbanaudit.org/CityProfiles.aspx [last visited 24.10.2013]
- Ecotect Research and Consulting (2007) “State of European Cities Report” European Union Regional Policy
- Eurostat (2013) Unemployment Statistics at Regional Level. European Commission. Online: epp.eurostat.ec.europa.eu/statistics_explained/index.php/Unemployment_statistics_at_regional_level [last visited 24.10.2013]

Density and population were estimated on the maps composed for figure 2-21, so that the same area was applicable to all regions. A table was done to compile all values. Then, for each column or indicator an icon was created and scaled relative to the maximum and minimum values among all cities. The colour gradient was designed to facilitate horizontal reading.

Fig. 2-24 Land use breakdown of the urban regions

Values were calculated from spatial analysis on maps made for figure 2-20, first in absolute terms and then as percentage.

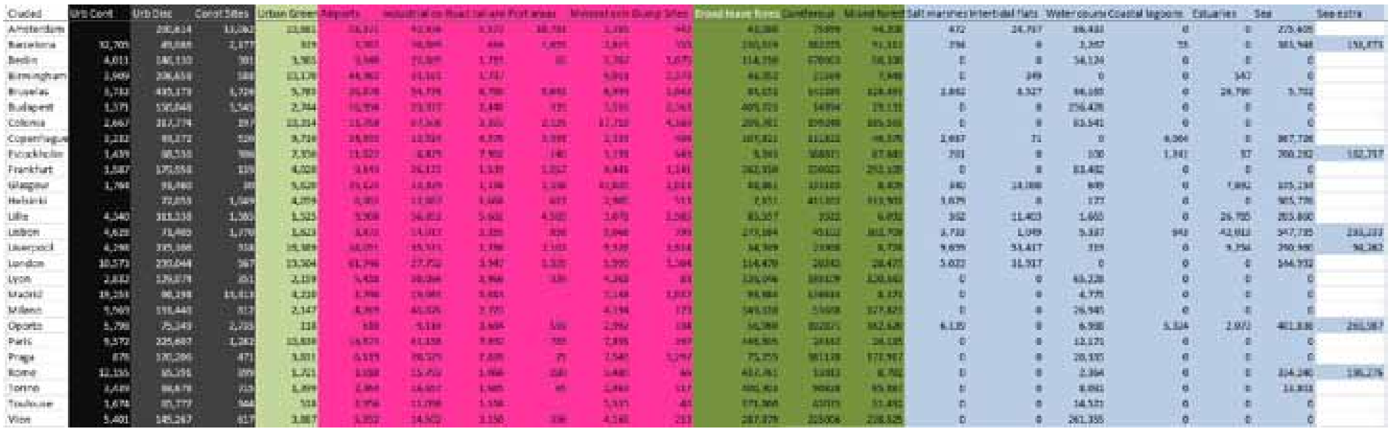


Fig.App-1 Spreadsheet compiling the area for each land use type in the regions

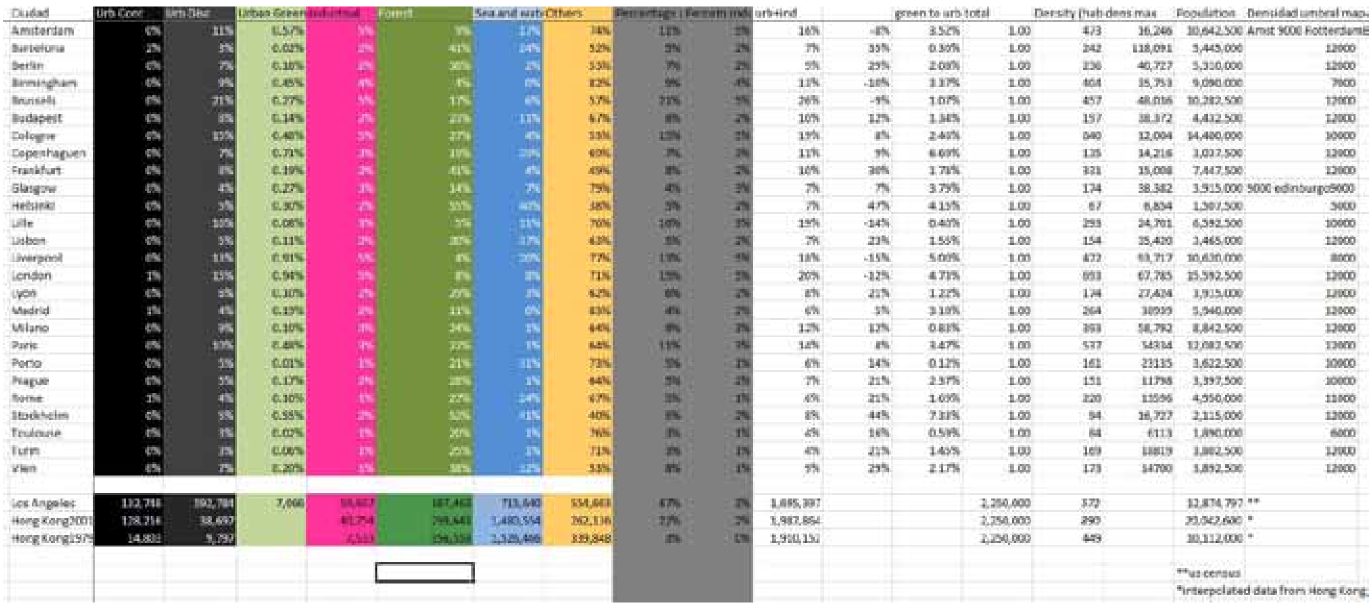


Fig.App-2 Spreadsheet calculating the percentage for each land use type in the regions

Fig. 2-25 Residential density distribution. Total people living in areas of each density range

Values were calculated from spatial analysis on maps made for figure 2-21 using ArcGIS and its raster summary statistics tool

European cit	Avg density region	People in 12(	6000-10000	4000-6000	-4000	Total Population
Helsinki	66	0	500,000	124,915	880,052	1,504,967
Toulouse	83	0	387,441	195,179	1,313,015	1,895,635
Stockholm	93	150,388	684,219	595,163	703,505	2,133,275
Copenhague	135	340,116	260,581	306,767	2,123,917	3,031,381
Prague	151	91,081	1,359,233	444,204	1,495,016	3,389,533
Lisbon	153	774,263	1,036,613	561,048	1,099,866	3,471,791
Oporto	161	84,427	931,203	766,234	1,901,299	3,683,163
Turin	169	335,431	1,181,372	645,076	1,681,809	3,843,688
Glasgow	174	61,813	588,586	1,472,236	1,821,206	3,943,842
Vienna	173	592,731	1,270,702	262,154	1,827,407	3,952,994
Lyon	174	678,230	571,766	454,980	2,259,170	3,964,145
Budapest	196	612,093	801,871	660,785	2,358,016	4,432,765
Rome	220	1,029,778	1,946,435	601,399	1,419,482	4,997,093
Berlin	235	466,657	2,891,511	258,433	1,696,947	5,313,548
Barcelona	241	2,901,330	1,163,403	367,730	1,049,475	5,481,938
Madrid	263	4,224,314	514,190	179,340	1,042,718	5,960,562
Lille	293	2,105	577,639	898,151	5,164,066	6,641,961
Frankfurt	331	99,346	2,060,226	1,830,742	3,535,800	7,526,115
Milan	392	836,255	2,285,575	2,537,135	3,251,325	8,910,289
Birmingham	403	5,347	722,083	4,313,453	4,143,674	9,184,557
Brussels	457	404,036	1,121,753	2,312,221	6,591,691	10,429,702
Amsterdam	473	1,181,520	3,258,285	4,134,037	2,085,302	10,659,143
Liverpool	472	9,180	1,687,441	5,814,593	3,187,898	10,699,112
Paris	537	3,609,754	3,963,308	1,839,990	2,778,124	12,191,176
Cologne	640	39,253	2,713,979	7,520,435	4,298,930	14,572,598
London	692	1,050,323	5,282,581	4,960,676	4,499,373	15,792,952

Fig.App-3 Spreadsheet compiling the population in each density range

Fig. 2-26 Residential density distribution. Residential density distribution. Percentage of population living in areas of each density range

Values were obtained by calculating each percentage from the previous table

European cit	Avg density region	People in 12(	6000-10000	4000-6000	-4000	Total Population	
Amsterdam	473	11%	31%	39%	20%	1	100%
Barcelona	241	53%	21%	7%	19%	1	100%
Berlin	235	9%	54%	5%	32%	5,313,548	100%
Birmingham	403	0%	8%	47%	45%	9,184,557	100%
Bruselas	457	4%	11%	22%	63%	10,429,702	100%
Budapest	196	14%	18%	15%	53%	4,432,765	100%
Colonia	640	0%	19%	52%	30%	14,572,598	100%
Copenhague	135	11%	9%	10%	70%	3,031,381	100%
Frankfurt	331	1%	27%	24%	47%	7,526,115	100%
Glasgow	174	2%	15%	37%	46%	3,943,842	100%
Helsinki	66	0%	33%	8%	58%	1,504,967	100%
Lille	293	0%	9%	14%	78%	6,641,961	100%
Lisbon	153	22%	30%	16%	32%	3,471,791	100%
Liverpool	472	0%	16%	54%	30%	10,699,112	100%
London	692	7%	33%	31%	28%	15,792,952	100%
Lyon	174	17%	14%	11%	57%	1	100%
Madrid	263	71%	9%	3%	17%	5,960,562	100%
Milano	392	9%	26%	28%	36%	8,910,289	100%
Paris	537	30%	33%	15%	23%	12,191,176	100%
Porto	161	2%	25%	21%	52%	3,683,163	100%
Praga	151	3%	40%	13%	44%	3,389,533	100%
Rome	220	21%	39%	12%	28%	4,997,093	100%
Stockholm	93	7%	32%	28%	33%	2,133,275	100%
Toulouse	83	0%	20%	10%	69%	1,895,635	100%
Turin	169	9%	31%	17%	44%	3,843,688	100%
Vien	173	15%	32%	7%	46%	3,952,994	100%

Fig.App-4 Spreadsheet compiling the population percentage in each density range

Fig. 2-27 Urban Structure: Percentage of tertiary within 1000 m to a residential area of density higher than 100ppha

The maps composed for figure 2-22 were used as base of the spatial analysis performed in ArcGIS 10.

1. First, those areas with residential density above 100ppha were selected
2. Then, a buffer zone was created to delimitate all commercial and industrial zones located within 1000m reach of the previous selection
3. Finally the proportion of the areas created in step 2 to the total industrial and commercial areas was calculated

European citi	Avg density region	People in 12(	6000-10000	4000-6000	-4000	Total Populat	Total comercial area	Commercial r	Commercial res den>100ppha	
Helsinki	66	0	500,000	124,915	880,052	1,504,967	103483806.1	100%	0%	100%
Toulouse	83	0	387,441	195,179	1,313,015	1,895,635	121275553.2	100%	0%	100%
Birmingham	403	5,347	722,083	4,313,453	4,143,674	9,184,557	142834028.3	99%	1%	100%
Frankfurt	331	99,346	2,060,226	1,830,742	3,535,800	7,526,115	178025635.3	97%	3%	100%
Prague	151	91,081	1,359,233	444,204	1,495,016	3,389,533	206971570.4	96%	4%	100%
Cologne	640	39,253	2,713,979	7,520,435	4,298,930	14,572,598	112274637.2	96%	4%	100%
Berlin	235	466,657	2,891,511	258,433	1,696,947	5,313,548	682721787.4	95%	5%	100%
Stockholm	93	150,388	684,219	595,163	703,505	2,133,275	131745585.5	93%	7%	100%
Copenhague	135	340,116	260,581	306,767	2,123,917	3,031,381	154669276.6	92%	8%	100%
Vien	173	592,731	1,270,702	262,154	1,827,407	3,952,994	142405817.6	91%	9%	100%
Lille	293	2,105	577,639	898,151	5,164,066	6,641,961	76585155.63	89%	11%	100%
Liverpool	472	9,180	1,687,441	5,814,593	3,187,898	10,699,112	72294213.11	88%	12%	100%
Glasgow	174	61,813	588,586	1,472,236	1,821,206	3,943,842	127013072.9	88%	12%	100%
Lyon	174	678,230	571,766	454,980	2,259,170	3,964,145	138468995.8	88%	12%	100%
London	692	1,050,323	5,282,581	4,960,676	4,499,373	15,792,952	541865609	87%	13%	100%
Turin	169	335,431	1,181,372	645,076	1,681,809	3,843,688	119986791.5	84%	16%	100%
Porto	161	84,427	931,203	766,234	1,901,299	3,683,163	48837451.95	81%	19%	100%
Paris	537	3,609,754	3,963,308	1,839,990	2,778,124	12,191,176	589942584.2	80%	20%	100%
Brussels	457	404,036	1,121,753	2,312,221	6,591,691	10,429,702	100522358.1	80%	20%	100%
Amsterdam	473	1,181,520	3,258,285	4,134,037	2,085,302	10,659,143	83893469	78%	22%	100%
Budapest	196	612,093	801,871	660,785	2,358,016	4,432,765	155832195.3	76%	24%	100%
Rome	220	1,029,778	1,946,435	601,399	1,419,482	4,997,093	185604302.5	71%	29%	100%
Milano	392	836,255	2,285,575	2,537,135	3,251,325	8,910,289	180895521.5	68%	32%	100%
Madrid	263	4,224,314	514,190	179,340	1,042,718	5,960,562	290239148.3	64%	36%	100%
Barcelona	241	2,901,330	1,163,403	367,730	1,049,475	5,481,938	146915902	56%	44%	100%
Lisbon	153	774,263	1,036,613	561,048	1,099,866	3,471,791	104336719.7	53%	47%	100%
								84%	16%	

Fig.App-5 Spreadsheet compiling the urban structure percentage

Fig. 2-28 European Cities. Comparative Data

Performance data sources are the same as for fig 2-23. Spatial analysis performed on maps 2-20 to 2-23 provided spatial variables. From these, some 25 correlation analysis between spatial and performance data were done using Microsoft Excel Dispersal Graphs. The final matrix shows a selection of the most relevant correspondences, but also where the lack of correlation was relevant for the discussion (e.g. GDP, living area per person...).

Once a correlation was detected in the preliminary analysis, the elasticity between variables was calculated, using the correlation formula, and compiled in a second table, before drawing up the final matrix

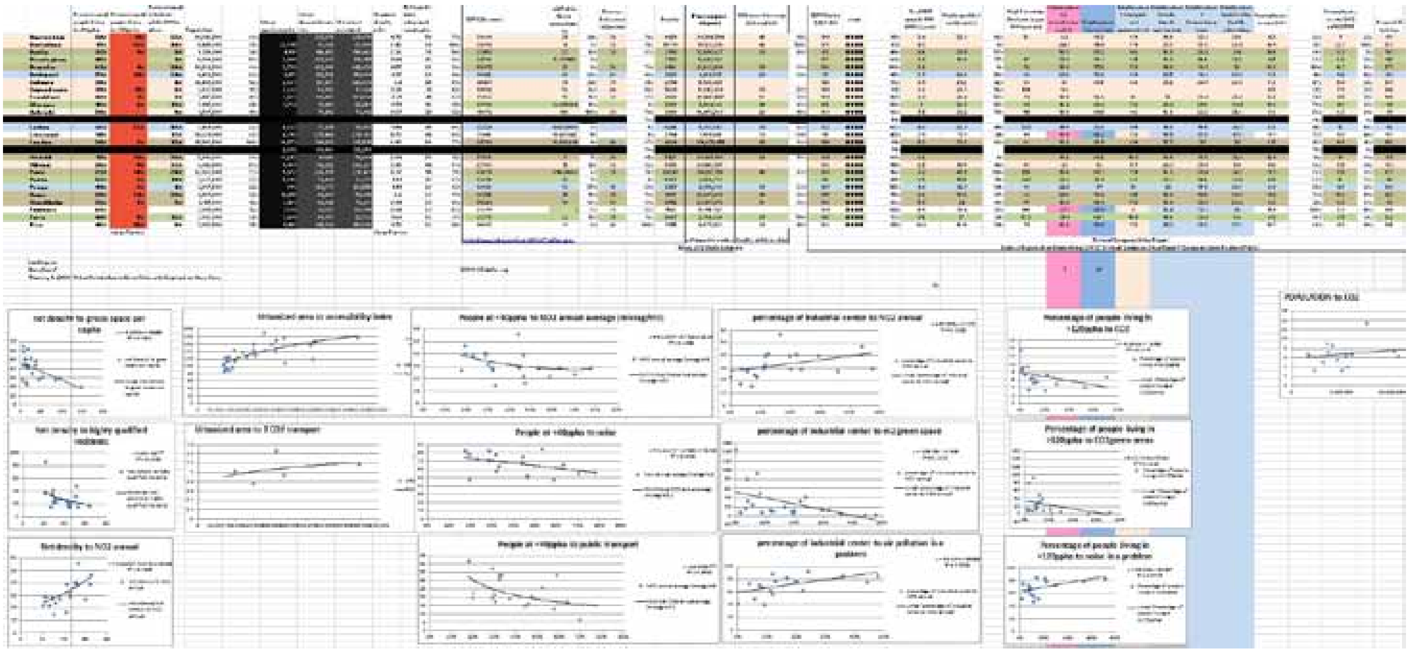


Fig.App-6 Snapshot of the Excel spreadsheet showing part of the background analysis to create the relational matrix of figure 2-28

Chapter 3: Sustainable City Paradigm as a Matter of Form

Fig 3-11 Some concepts involved in Sustainable City definition according to experts

These data has been obtained from an enquiry conducted by the Danish Architecture Centre and it is available online at:

- http://sustainablecities.dk/en/experts [last access at 10/09/2012]

The answers were collected from the website and processed with MS Word by a Macro to obtain the frequency of the words. Irrelevant words were remove and the remaining ones were processed with Wordaizer to draw the “wordcloud”. The final result was fine-tuned using Adobe Illustrator.

List of experts (alphabetical order):

1. Arun Jain , urban designer
2. Barbara Southworth, urban designer
3. Cameron Sinclair, architect
4. David Harvey, geographer and social theorist
5. Govert Geldof, water engineer
6. Herbert Girardet, ecological researcher,World Future Council
7. Hilmar von Lojewski, urban planner
8. Jan Gehl, architect and urban designer
9. Janette Sadik-Khan, Transportation Commissioner NYC
10. Joan Busquets, professor, architect and planner
11. John Whitelegg, professor of Sustainable Development
12. Leo Abruzzese, Economist Intelligence Unit
13. Luciano Ducci, mayor of Curitiba
14. Mathis Wackernagel, professor,Global Footprint Network
15. Pan Haixiao, professor of Land Use and Transport Studies
16. Peter Newman, environmental scientist
17. Richard Burdett, professor of Urban Studies, LSE
18. Thomas Ermacora, urbanist and geographer
19. Thomas Sieverts, architect and planner
20. Vandana Shiva, activist and philosopher

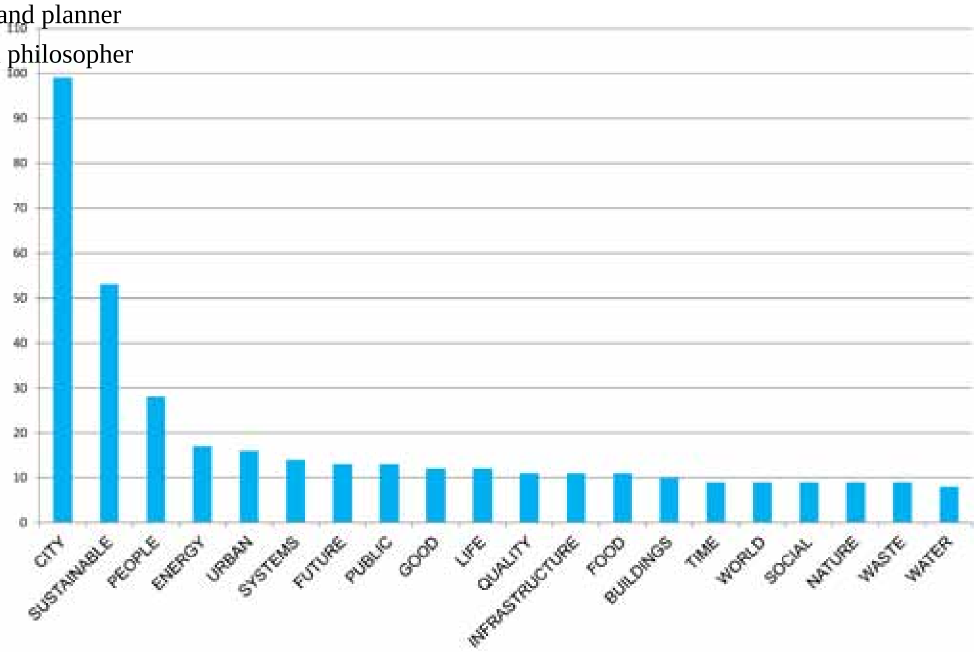


Fig.App-7 Frequency of 20 most repeated words (in number of appearances)

Fig 3-14 Decentralization of housing construction in Spain between 1991 and 2001

Data were obtained from the Spanish Census of 1991 and 2001. The population of the country was aggregated by the size of municipalities, so that the demographic evolution of the period could be calculated.

- http://www.ine.es/censo/es/listatablas.jsp?table=tablas/nacional/NE6.html [last accessed 20.12.2013]

@INE 2004. Censos de Población y Viviendas 1991. Resultados

Ambito geo	Nacional	
Colectivo	Todas las personas	
Filas	Tamaño municipio de residencia	
Columnas		
Unidad de n	Personas	
Filtros		
Tamaño municipio de residencia		
TOTAL	38872268	
Menos de 10	49195	0.13%
De 101 a 500	757377	1.95%
De 501 a 1.0	833433	2.14%
De 1.001 a 2	1475002	3.79%
De 2.001 a 5	3131825	8.06%
De 5.001 a 1	3484076	8.96%
De 10.001 a	4158075	10.70%
De 20.001 a	5011617	12.89%
De 50.001 a	3601953	9.27%
De 100.001 a	9163242	23.57%
Más de 500.(	7206473	18.54%
<5000	6246832	16.07%
5000-100000	16255721	41.82%
>100000	16369715	42.11%
		100.00%

@INE 2004. Censos de Población y Viviendas 2001. Resultados definitivos.

Ambito geo	Nacional	
Colectivo	Todas las personas	
Filas	Tamaño municipio de residencia	
Columnas		
Unidad de n	Personas	
Filtros		
Tamaño municipio de residencia		
TOTAL	40847371	
Menos de 10	60396	0.15%
De 101 a 500	714260	1.75%
De 501 a 1.0	796662	1.95%
De 1.001 a 2	1426139	3.49%
De 2.001 a 5	3156725	7.73%
De 5.001 a 1	3497229	8.56%
De 10.001 a	4673214	11.44%
De 20.001 a	5839977	14.30%
De 50.001 a	4231284	10.36%
De 100.001 a	9446485	23.13%
Más de 500.(	7005000	17.15%
<5000	6154182	15.07%
5000-100000	18241704	44.66%
>100000	16451485	40.28%

Variación Censos de Población y Viviendas 1991-2001

Tamaño municipio de residencia			
TOTAL	1975103	cambio %	cambio en relacion al total
Menos de 10	11201	22.77%	0.02%
De 101 a 500	-43117	-5.69%	-0.20%
De 501 a 1.0	-36771	-4.41%	-0.19%
De 1.001 a 2	-48863	-3.31%	-0.30%
De 2.001 a 5	24900	0.80%	-0.33%
De 5.001 a 1	13153	0.38%	-0.40%
De 10.001 a	515139	12.39%	0.74%
De 20.001 a	828360	16.53%	1.40%
De 50.001 a	629331	17.47%	1.09%
De 100.001 a	283243	3.09%	-0.45%
Más de 500.(	-201473	-2.80%	-1.39%
<5000	-92650	-1.48%	-1.00%
5000-100000	1985983	12.22%	2.84%
>100000	81770	0.50%	-1.84%

Fig.App-8 Spreadsheet showing the calculation using Census data

Chapter 4: Buildings' Energy and Urban Form

Fig. 4.10 Surface heat budget in central Tokyo for shortwave radiation and anthropogenic heat

Data obtained from:

- Ichinose, T. Shimodozono, K. & Hanaki, K. (1999) Impact of anthropogenic heat or urban climate in Tokyo. Atmospheric Environment n.33 pp.3897-3909. Pergamon

Plotted an processed in MS Excel

	Surface Heat Budget in central Tokyo			
	Summer		Winter	
	Shortwave (r	Anthropoge	Shortwave (r	Anthropogenic heat
0	0	10	0	20
1	0	5	0	20
2	0	5	0	20
3	0	5	0	20
4	0	5	0	20
5	0	10	0	30
6	160	30	0	60
7	330	100	0	280
8	500	200	160	500
9	625	190	295	450
10	750	195	430	400
11	796	200	476	390
12	820	195	500	380
13	796.666667	194	476	400
14	750	180	430	350
15	625	195	295	320
16	500	185	160	350
17	330	175	0	300
18	160	150	0	200
19	80	110	0	150
20	0	90	0	120
21	0	70	0	110
22	0	60	0	90
23	0	20	0	30

Fig.App-9 Values to plot graphs in figure 4.10

Fig. 4.11 Anthropogenic heat emissions in Greater London, annual average

Data generated with Greater QF software, Department of Geography King's College London.

Processed and plotted by the author in GvSIG

- http://geography.kcl.ac.uk/micromet/index.htm [last accessed 20.12.2013]

Fig. 4.16 Variation in primary energy for heating and cooling when the effect of UHI is considered, for (imaginary) urban areas in London and Barcelona

To estimate the potential impact of the Urban Heat Island in the energy demand four runs were conducted in the UEI tool. The Urban Heat Island was estimated by selecting a weather station at the city centre and a rural location.

In Barcelona, the stations were:

- Barcelona City 41.42ºN 2.13ºE Altitude=10m
- Barcelona Airport 41.283ºN 2.067ºE Altitude=6m

For London:

- London Weather C. 51.517ºN 0.117ºW Altitude=77m
- Barking and Dagenham 51.550ºN 0.12ºW Altitude=15m

The UHI was then applied on the weather data embedded in Climatelite as used in the UEI. In each run, the weather data was modified to represent the following conditions

- Step 1: London
- Step 2: London with UHI difference
- Step 3: Barcelona
- Step 4: Barcelona with UHI difference

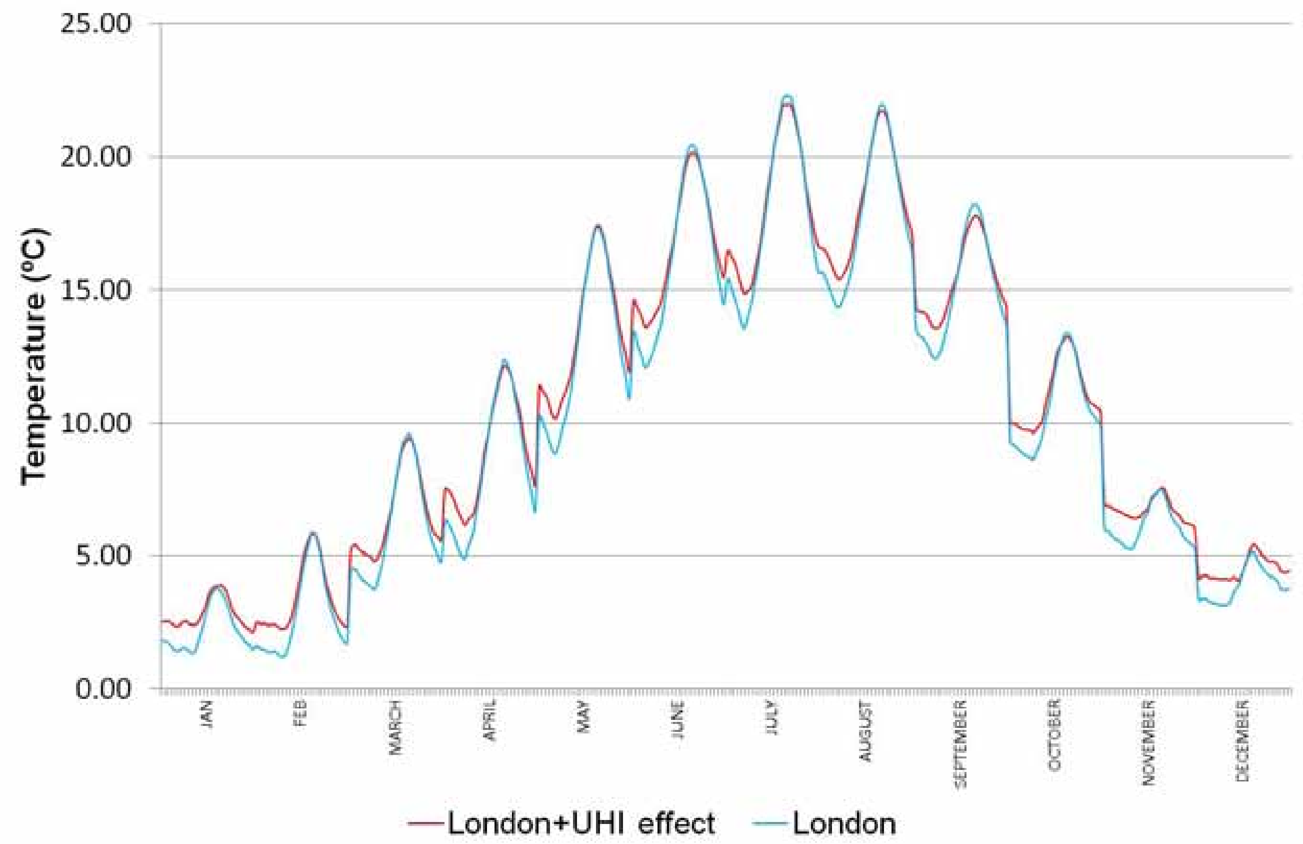


Fig.App-10 Weather data used for London. Hourly average temperature

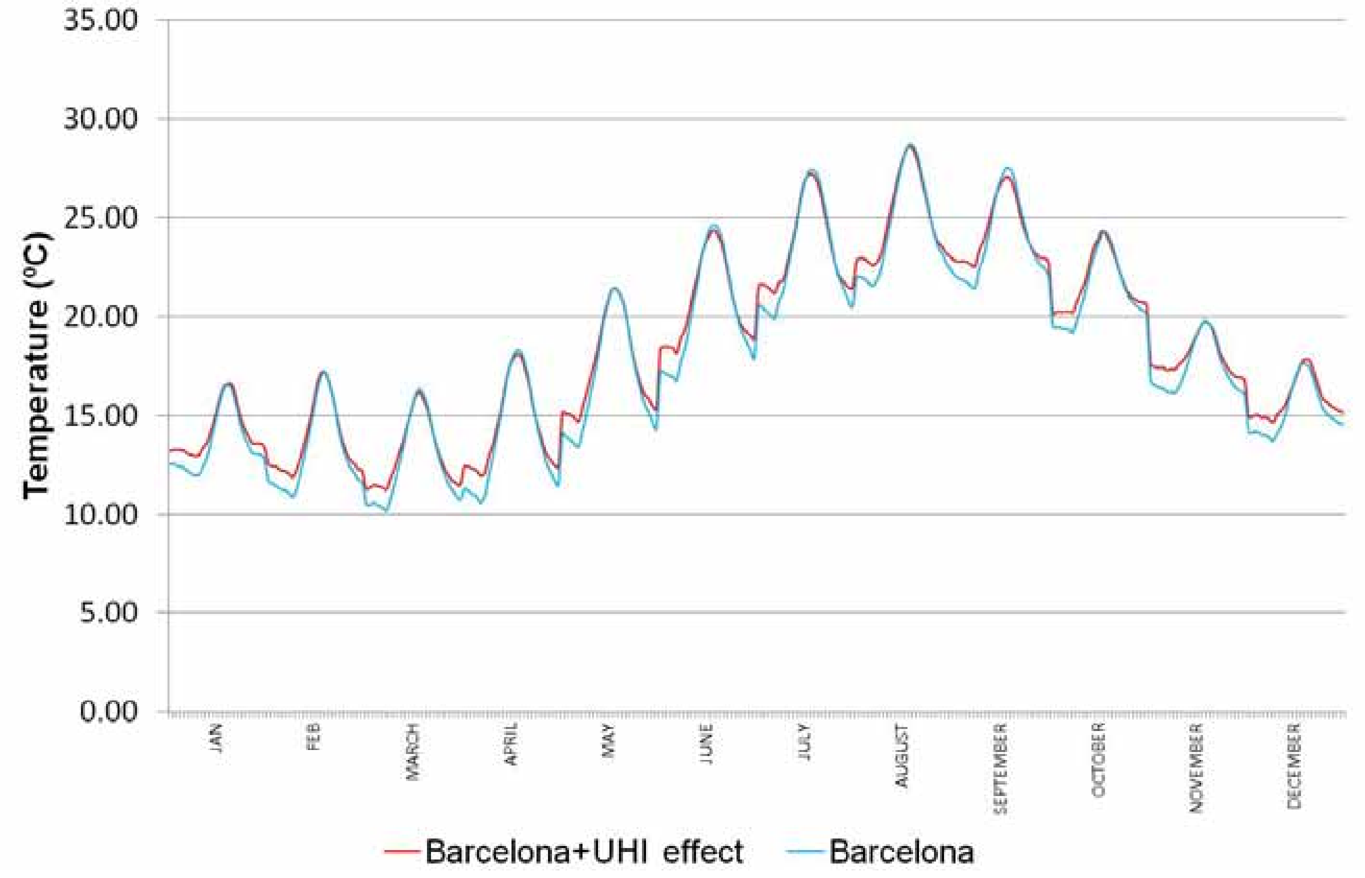


Fig.App-11 Weather data used for Barcelona. Hourly average temperature

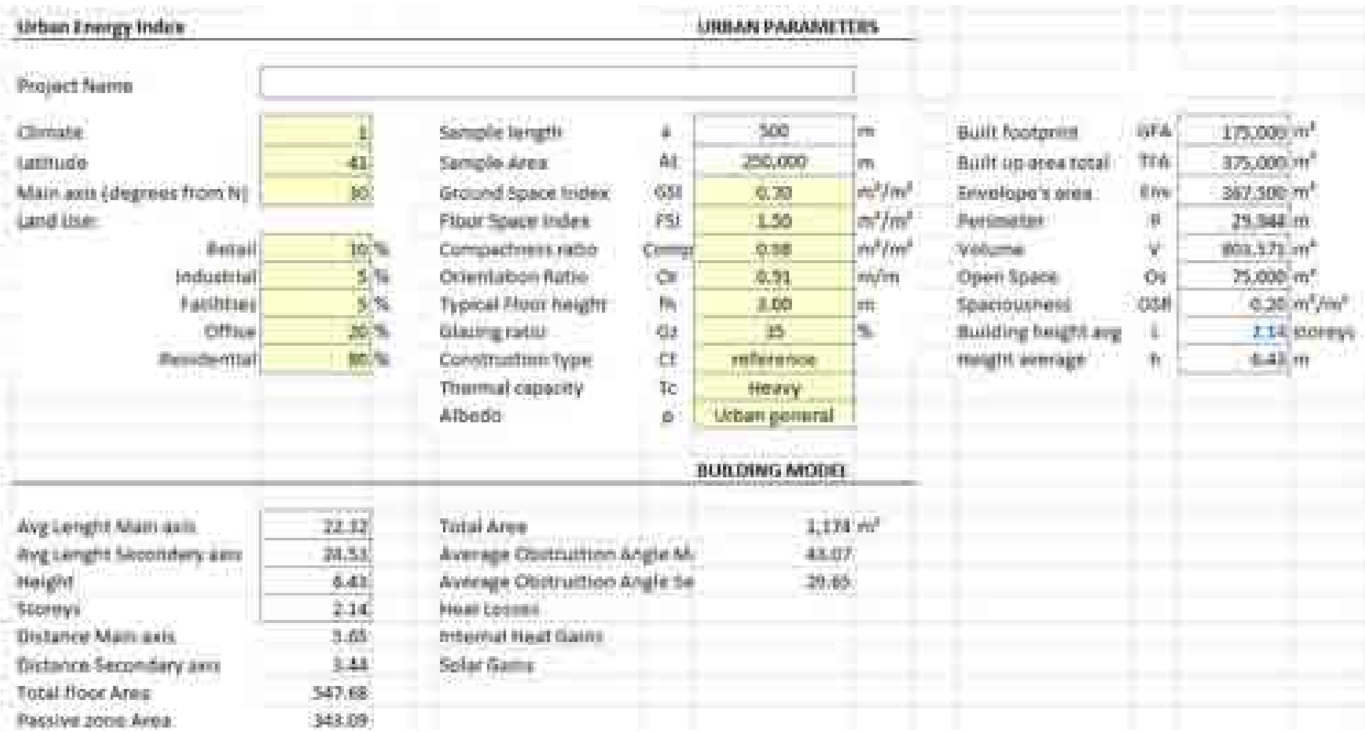


Fig.App-12 Input parameters used in UEI calculations (Climate and latitude were adjusted for each location and simulation, for assumptions and default UEI parameters see the corresponding chapter)

Fig. 4.17 Land Cover (top) and Land Surface Temperature for a summer night (bottom) in six European regions.

Land surface temperature was extracted from Satellite Modis, processed and plotted in GvSIG in the following steps:

1. Satellite images were downloaded from www.earthexplorer.usgs.gov. The dataset was MODIS MOD 11A2, which contains information on global land surface temperature, daytime and night-time average of 8 days. Modis data is in hdf format, which is a raster mosaic. Each tile covered 10x10º. Six tiles were necessary to cover the main European capitals.
2. The images were reprojected with Modis Reprojection Tool (lpdaac.usgs.gov/tools/modis_reprojection_tool [last accessed 19.12.2013]). Land Surface Temperature LST_Day_1Km and LST_Night_1Km bands were selected and saved as geotiffs with a Gegraphic projection WGS84
3. The next step consisted on the selection of clear days and nights, since clouds intercept the signal and create patches without information. For winter, it was necessary to check 7 different days for each of the 6 tiles: 2^{nd}, 10^{th}, 15^{th} and 31^{st} of October of 2004, 16th November and 2^{nd} and 10^{th} of December. The 10th of October was the day with the clearest sky in most areas, although 16^{th} of November was also used.For summer, three days were checked: 6^{th} of June, 7^{th} July and 27^{th} of July. The former date presented the clearest conditions except for two tiles, which required the use of data from the 6^{th} of June, all of them from 2004.
4. After selecting and clipping the day and nights with the best conditions to visualize the UHI. Since original data was Kelvin degrees, they were transformed to Celsius, using the map calculator tool in Sextante. A colour scale was used to portray thermal differences and plotted in GvSIG.

Fig. 4.18 UHI against density in six European capitals

Data from density and land surface temperature were obtained from maps 2-16 and 4-27 respectively. Their profiles were drawn with profile tool in Sextante, exported to MSExcel to produce a graph. Finally, the graph was redrawn in Adobe Illustrator

Fig. 4.19 UHI against land use in four European capitals

Data for land use types was obtained from the Urban Atlas.

- www.eea.europa.eu/data-and-maps/data/urban-atlas [last accessed 20.12.2013]

The division grouped several Corine categories into more general fields:

ITEM	
Agricultural + Semi-natural areas + Wetlands	Agricultural
Agricultural + Semi-natural areas + Wetlands	Agricultural
Other roads and associated land	Artificial
Discontinuous Dense Urban Fabric (S.L. : 50% - 80%)	Artificial
Discontinuous Medium Density Urban Fabric (S.L. : 30% - 50%	Artificial
Industrial, commercial, public, military and private units	Artificial
Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)	Artificial
Discontinuous Very Low Density Urban Fabric (S.L. < 10%)	Artificial
Isolated Structures	Artificial
Continuous Urban Fabric (S.L. > 80%)	Artificial
Railways and associated land	Artificial
Construction sites	Artificial
Mineral extraction and dump sites	Artificial
Fast transit roads and associated land	Artificial
Forests	Forests
Green urban areas	Green urban areas
Land without current use	Land without current use
Sports and leisure facilities	Sports and leisure facilities
Water bodies	Water bodies

The land use band was 50x8 cells. For each cell, a break down was calculated and plotted into the profile a percentage of each land use type

Fig.App-13 Example of Land Use type breakdown calculation: The spreadsheet contains the area for each use in each cell. The coloured rows are summary statistic for each section and type.

Chapter 5: Urban Form and the Impact of Travel

Fig. 5-14 Influence of urban form and land use aspects in travel patterns according to the analysis of previous studies

The following studies were analyzed to compile the mobility matrix:

1. Albalate, D. & Bel, G. (2009) Factors Explaining Urban Transport Systems in Large European Cities: A Cross-Sectional Approach. Research Institute of Applied Economics. Working Papers 2009/05
2. ATM(2008) Pla Director de Mobilitat de la Regió Metropolitana de Barcelona. Autoritá del Transpot Metropolitá
3. Bannister, D. (2008) The Sustainable Mobility Paradigm. Transport Policy 15 pp. 73-80
4. Bannister, D. (2011) Cities, Mobility and Climate Change. Journal of Transport Geography, n 19 pp.1538-1546
5. Bertolini, L. (2005) The Multi-Modal Urban Region: A Concept to Combines Environmental and Economic Goals. In Jenks,M. & Dempsey, N. (2005) Future Forms. Design for Sustainable Cities. Architectural Press
6. Breheny (1995) The Compact City and Transport Energy Consumption. Transactions of the Institute of British Geographers, New Series, Vol. 20, No. 1 pp. 81-101
7. Buxton, M. (2000) Energy, Transport and Urban Form in Australia. Williams, K. Burton, E. Jenks, M. eds. (2000) Achieving Sustainable Urban Form. E&F N Spon
8. Camagni, R. Gibelli, M.C. Rigamonti, P. (2002) Urban Mobility and Urban Form: The Social and Environmental Costs of Different Patterns of Urban Expansion. Ecological Economics 40 pp. 199-216
9. Cervero, R. & Kockelman, K. (1997) Travel Demand and the 3Ds: Density, Diversity and Design. Transportation Research.-D, Vol. 2, No. 3, pp. 199-219
10. Ewing, R. & Robert Cervero, R. (2010): Travel and the Built Environment, Journal of the American Planning Association,76:3, pp. 265-294
11. Hedel, R. & Vance, C. (2007) The Impact of Urban Form on Automobile Travel: Disentangling Causation from Correlation. Transportation 32:575-588. Springer
12. Hickman, R. & Banister, D. (2007) Transport and Reduced Energy Consumption: What Role Can Urban Planning Play. University of Oxford. Transport Studies Unit. Working Paper Nº106
13. Karathodorou, N. Graham, D.J. and Noland, R.B. (2010) Estimating the effect of urban density on fuel demand. Energy Economics, Vol.32 1 pp. 86-92
14. Masnavi, M. R. (2000) The New Millennium and the New Urban Paradigm. The Compact City in Practice. In Williams, K. Burton, E. Jenks, M. eds. (2000) Achieving Sustainable Urban Form. E&F N Spon
15. Minaldi, O. Raveh, A. Salomon, I. (2004) Urban Density and Energy Consumption: A New Look to Old Statistics. Transportation Research Part A 38 pp.143-162

16. Muñiz, I. & Galindo, A. (2005) Urban Form and the Ecological Footprint of Commuting. The Case of Barcelona. Ecological Economics 55 pp. 499-514
17. Naes, R. (2005) Residential Location Affects Travel Behavior: But How and Why? The Case of Copenhagen Metropolitan Area. Progress in Planning. Vol 63 N.2 pp. 167-257
18. Newman, P. & Kenworthy, J. (1989) Cities and Automobile Dependence: An international Sourcebook. Gower
19. Newman, P. & Kenworthy, J. (2000) Sustainable Urban Form. The Big Picture. In Williams, K. Burton, E. Jenks, M. eds. (2000) Achieving Sustainable Urban Form. E&F N Spon
20. Newton, M. (2000) Urban Form and Environmental Performance. In Williams, K. Burton, E. Jenks, M. eds. (2000) Achieving Sustainable Urban Form. E&F N Spon
21. Smith, D.A. (2011) Polycentricity and Sustainable Urban Form. An Intra-Urban Study of Accessibility, Employment and Travel Sustainability for the Strategic Planning of the London Region. PhD Thesis at UCL Bartlett Centre of Advanced Spatial Analysis
22. Snellen, D. (2002) Urban Form and Activity-Travel Patterns. An Activity-Based Approach to Travel in a Spatial Context. PhD thesis Technische Universiteit Eindhoven

From these, only six were found useful for to obtain correlations: Hedel & Vance, 2007, Hickman & Bannister, 2007 Masnavi, 2000 Muñiz & Galindo, 2005 Naes, 2005 and Snellen, 2002

Elasticities between morphological variables and transport indicators were summarized in tables and compared against the meta study undertaken in Ewing & Cervero, 2010

The values in table 2 were used to size the proportion and color of rectangles in the matrix

Table.App-1 Elasticity factors and number of samples from Ewing & Cervero 2010 report (Ewing & Cervero, 2010) e(E&C)= elasticity according to Ewing and Cervero, N=number of studies

	Motorised travelled distance		**Probability of walking**		**Probability of use of Public Transport**	
x	***e (E&C)***	***N***	***e (E&C)***	***N***	***e (E&C)***	***N***
Household/population density	-0.04	9	0.07	10	0.07	10
Job density	0	6	0.04	6	0.01	6
Commercial floor area ratio			0.07	3		
Land use mix	-0.09	10	0.15	8	0.12	6
Jobs-housing balance	-0.02	4	0.19	4	0.23	4
Distance to a store			-0.25	5		
Intersection/street density	-0.12	6	0.39	7	0.29	5
% 4-way intesections	-0.12	3	0.06	5		
Job accessibility by auto	-0.2	5				
Job accessibility by public transport	-0.05	3				
Distance to city center	0.22	3				
Distance to nearest public transport stop	-0.05	6	-0.15	3	-0.29	3

Table.App-2 Elasticity factors and correlations from different European transport studies. Comparison with Ewing & Cervero elasticity N= number of observation y= transport indicator x=urban form parameter e(E&C)= elasticity according to Ewing and Cervero, e=elasticity according to author's study

Study	*N*	*y*	*x*	*e (E&C)*	*e*	*P (Pearson Correlation)*
Muñiz and Galindo, 2005	Census	Average Trip Distance	Population Density		-0.19	
Muñiz and Galindo, 2005	Census	Average Trip Distance	Average household income		0.61	
Hickmand and Banister, 2007	1653	Average Trip Distance	Distance to City Centre			0.143
Muñiz and Galindo, 2005	Census	Average Trip Distance	Distance to City Centre		0.23	
Muñiz and Galindo, 2005	Census	Average Trip Distance	Distance to Transport Axis		0.13	
Muñiz and Galindo, 2005	Census	Average Trip Distance	Job ratio		-0.17	
Hickmand and Banister, 2007	1653	Average Trip Distance	Jobs-housing balance			0.008
Hickmand and Banister, 2007	1653	Average Trip Distance	Population Density			-0.058
Hickmand and Banister, 2007	1653	Average Trip Distance	Public Transport Accessibility			0.073
Hickmand and Banister, 2007	1653	Average Trip Distance	Residential Population Size			0.001
Hickmand and Banister, 2007	1653	Energy Consumption	Population Density			-0.132
Hickmand and Banister, 2007	1653	Energy Consumption	Jobs-housing balance			0.011
Hickmand and Banister, 2007	1653	Energy Consumption	Public Transport Accessibility			0.117
Hickmand and Banister, 2007	1653	Energy Consumption	Distance to City Centre			0.179
Hickmand and Banister, 2007	1653	Energy Consumption	Residential Population Size			-0.024
Masnavi, 2000	327	Motorised travelled distance	Population Density	-0.04	-0.35	
Snellen, 2002	436	Motorised travelled distance	Population Density City	-0.04	0.03	
Snellen, 2002	436	Motorised travelled distance	Population Density Neighborhood	-0.04	-0.03	
Hedel & Vance, 2007	28901	Motorised travelled distance	Land Use Mix	-0.09	-0.06	
Snellen, 2002	436	Motorised travelled distance	Distance to Station	-0.05	0.07	
Hedel & Vance, 2007	28901	Motorised travelled distance	Distance to Station	-0.05	-0.02	
Snellen, 2002	436	Motorised travelled distance	Distance to City Centre	-0.22	0.08	
Snellen, 2002	436	Motorised travelled distance	Degree Urbanization City		-0.05	
Snellen, 2002	436	Motorised travelled distance	Degree Urbanization Neighborhood		0.11	
Hedel & Vance, 2007	28901	Motorised travelled distance	Street Density	-0.12	-0.04	
Masnavi, 2000	327	Percentage of trips by Public Transport	Population Density	0.07	0.38	
Muñiz and Galindo, 2005	Census	Proportion of trips by car	Population Density		-0.29	
Muñiz and Galindo, 2005	Census	Proportion of trips by car	Job ratio		0.04	
Muñiz and Galindo, 2005	Census	Proportion of trips by car	Distance to Transport Axis		0.05	
Muñiz and Galindo, 2005	Census	Proportion of trips by car	Distance to City Centre		0.1	
Muñiz and Galindo, 2005	Census	Proportion of trips by car	Average household income		0.56	
Snellen, 2002	436	Total travelled distance	Housing Density		-0.05	
Snellen, 2002	436	Total travelled distance	Population Density City		-0.05	
Snellen, 2002	436	Total travelled distance	Population Density Neighborhood		-0.01	
Snellen, 2002	436	Total travelled distance	Distance to Station		-0.08	
Snellen, 2002	436	Total travelled distance	Distance to City Centre		-0.06	
Snellen, 2002	436	Total travelled distance	Degree Urbanization City		0.09	
Snellen, 2002	436	Total travelled distance	Degree Urbanization Neighborhood		-0.05	
Snellen, 2002	436	Vehicle Miles Travelled	Household/Population Density	-0.04	-0.04	
Naes, 2005	1414	Weekday travel distance by car per person	Distance to Station	-0.05	-0.14	
Naes, 2005	1414	Weekday travel distance by car per person	Distance to City Centre		-0.27	

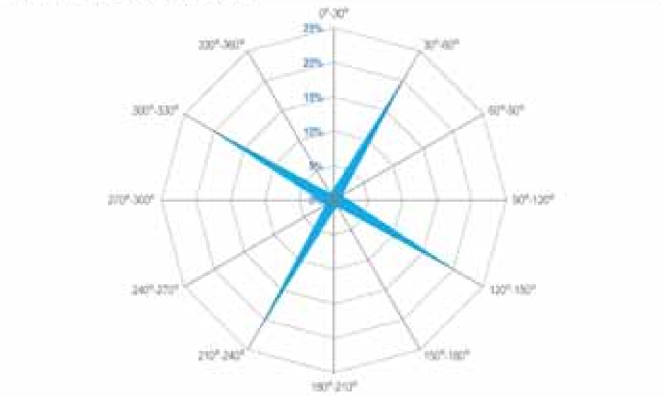
Chapter 6: An Urban Form Energy Analysis and Model

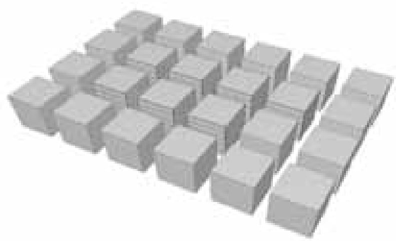
Data sheets for urban samples, showing morphological parameters as calculated from the real urban fabric. These values were then used in the UEI analysis:

BCN EIXAMPLE

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	129,505	m²	GIS
Built up area total	TFA	707,985	m²	GIS
Envelope's area	Env	704,534	m²	GIS
Volume	V	2,122,751	m³	GIS
Orientation Ratio	Or	1.00	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	120,495	m²	At-GFA
Perimeter	P	35,062	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	17,558	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	17,504	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.00	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.52	m²/m²	GFA/At
Floor Space Index	FSI	2.83	m²/m²	TFA/At
Building height avg	L	5.47	storeys	FSI/GSI
Height average	h	16.40	m	L*fh
Spaciousness	OSR	0.17	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	14.80	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	14.75	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	593.27		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	24.36		nr=sqrt (P^2*Or /(4GFA*(1+Or)^2))
Average distance Main axis	dm	5.73	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	5.78	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	70.74	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	70.60	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	2.86	m/m	h/dm
Average urban canyon main	Ucs	2.84	m/m	h/ds
Passive Zone	PZ	124,938	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.96	m²/m²	PZ/GFA
Model floor height	fh'	3.28	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

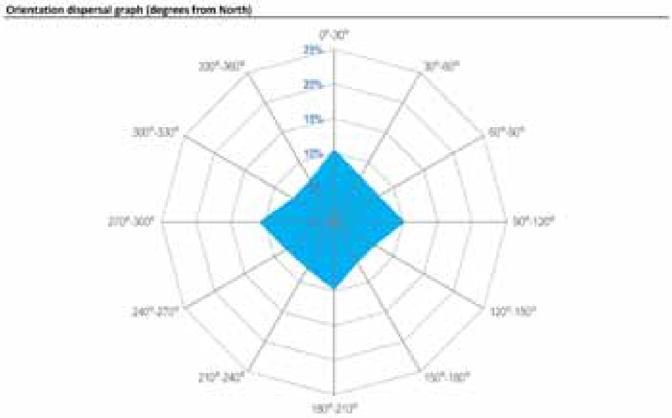


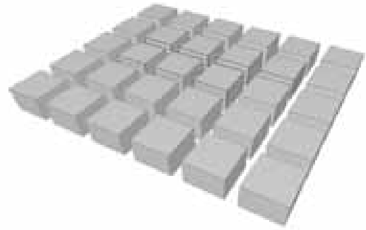


BCN SANTS-BADAL

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	145,463	m²	GIS
Built up area total	TFA	569,282	m²	GIS
Envelope's area	Env	609,209	m²	GIS
Volume	V	1,822,532	m³	GIS
Orientation Ratio	Or	0.98	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	104,537	m²	At-GFA
Perimeter	P	39,499	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	19,599	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	19,900	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.07	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.58	m²/m²	GFA/At
Floor Space Index	FSI	2.28	m²/m²	TFA/At
Building height avg	L	3.91	storeys	FSI/GSI
Height average	h	11.74	m	L*fh
Spaciousness	OSR	0.18	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	14.62	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	14.84	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	670.30		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	25.89		nr=sqrt (P^2*Or /(4GFA*(1+Or)^2))
Average distance Main axis	dm	4.69	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	4.47	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	68.21	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	69.16	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	2.50	m/m	h/dm
Average urban canyon main	Ucs	2.63	m/m	h/ds
Passive Zone	PZ	140,470	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.97	m²/m²	PZ/GFA
Model floor height	fh'	3.91	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

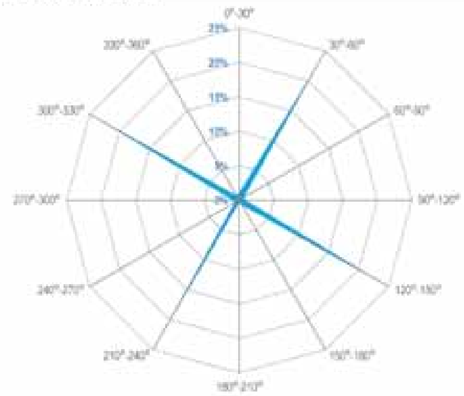


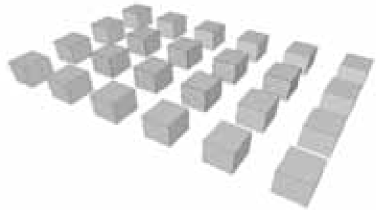


Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	57,806	m^2	GIS
Built up area total	TFA	287,203	m^2	GIS
Envelope's area	Env	281,475	m^2	GIS
Volume	V	860,605	m^3	GIS
Orientation Ratio	Or	0.91	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	192,194	m^2	At-GFA
Perimeter	P	15,006	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	7,156	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	7,850	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.98	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.23	m^2/m^2	GFA/At
Floor Space Index	FSI	1.15	m^2/m^2	TFA/At
Building height avg	L	4.97	storeys	FSI/GSI
Height average	h	14.91	m	L*fh
Spaciousness	OSR	0.67	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	14.73	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	16.16	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	242.95		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	15.59		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	17.35	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	15.92	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	40.66	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	43.11	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.86	m/m	h/dm
Average urban canyon main	Ucs	0.94	m/m	h/ds
Passive Zone	PZ	55,058	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.95	m^2/m^2	PZ/GFA
Model floor height	fh'	3.73	m	fh'= h/integer (L)

BCN EL BESÓS I EL MARESME

Orientation dispersal graph (degrees from North)

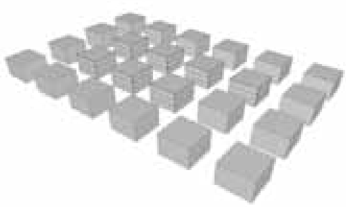




Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	75,470	m^2	GIS
Built up area total	TFA	235,728	m^2	GIS
Envelope's area	Env	323,900	m^2	GIS
Volume	V	81,151	m^3	GIS
Orientation Ratio	Or	1.03	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	174,530	m^2	At-GFA
Perimeter	P	26,512	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	13,465	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	13,047	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.37	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.30	m^2/m^2	GFA/At
Floor Space Index	FSI	0.94	m^2/m^2	TFA/At
Building height avg	L	3.12	storeys	FSI/GSI
Height average	h	9.37	m	L*fh
Spaciousness	OSR	0.74	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	11.57	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	11.21	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	581.95		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	24.12		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	9.16	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	9.52	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	45.66	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	44.56	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	1.02	m/m	h/dm
Average urban canyon main	Ucs	0.98	m/m	h/ds
Passive Zone	PZ	75,271	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	1.00	m^2/m^2	PZ/GFA
Model floor height	fh'	3.12	m	fh'= h/integer (L)

BCN LA FONT D'EN FARGUES

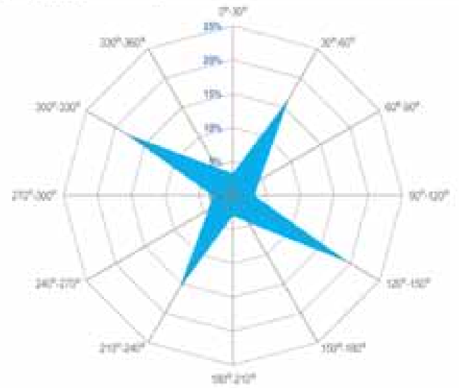
Orientation dispersal graph (degrees from North)

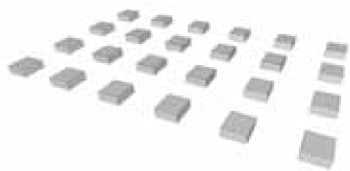


BCN PEDRALBES

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	36,317	m^2	GIS
Built up area total	TFA	73,733	m^2	GIS
Envelope's area	Env	97,756	m^2	GIS
Volume	V	220,912	m^3	GIS
Orientation Ratio	Or	0.91	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	213,683	m^2	At-GFA
Perimeter	P	10,087	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	4,796	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	5,291	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.33	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.15	m^2/m^2	GFA/At
Floor Space Index	FSI	0.29	m^2/m^2	TFA/At
Building height avg	L	2.03	storeys	FSI/GSI
Height average	h	6.09	m	L*fh
Spaciousness	OSR	2.90	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	13.73	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	15.15	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	174.68		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	13.22		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	24.10	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	22.69	m	ds=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	14.18	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	15.03	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.25	m/m	h/dm
Average urban canyon main	Ucs	0.27	m/m	h/ds
Passive Zone	PZ	35,368	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.97	m^2/m^2	PZ/GFA
Model floor height	fh'	3.05	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

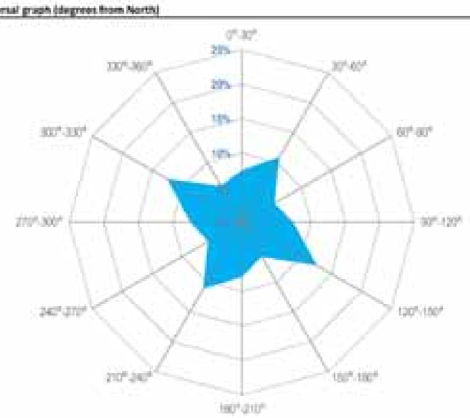




BCN LES PLANES

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	11,180	m^2	GIS
Built up area total	TFA	15,188	m^2	GIS
Envelope's area	Env	34,057	m^2	GIS
Volume	V	45,526	m^3	GIS
Orientation Ratio	Or	0.97	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	238,820	m^2	At-GFA
Perimeter	P	5,613	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	2,759	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	2,854	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	2.24	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.04	m^2/m^2	GFA/At
Floor Space Index	FSI	0.06	m^2/m^2	TFA/At
Building height avg	L	1.36	storeys	FSI/GSI
Height average	h	4.08	m	L*fh
Spaciousness	OSR	15.72	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	7.83	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	8.10	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	176.08		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	13.27		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	29.85	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	29.58	m	ds=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	7.78	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	7.85	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.14	m/m	h/dm
Average urban canyon main	Ucs	0.14	m/m	h/ds
Passive Zone	PZ	8,322	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.74	m^2/m^2	PZ/GFA
Model floor height	fh'	4.08	m	fh'= h/integer (L)

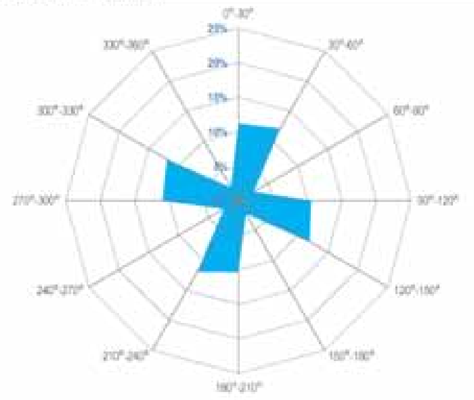
Orientation dispersal graph (degrees from North)

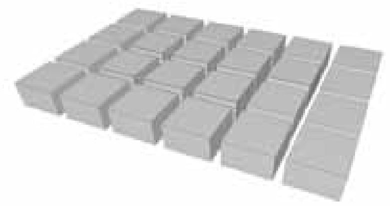


MAD EMBAJADORES

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	174,093	m^2	GIS
Built up area total	TFA	813,748	m^2	GIS
Envelope's area	Env	672,652	m^2	GIS
Volume	V	2,437,658	m^3	GIS
Orientation Ratio	Or	0.99	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	75,907	m^2	At-GFA
Perimeter	P	35,554	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	17,670	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	17,884	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.83	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.70	m^2/m^2	GFA/At
Floor Space Index	FSI	3.25	m^2/m^2	TFA/At
Building height avg	L	4.67	storeys	FSI/GSI
Height average	h	14.02	m	L*fh
Spaciousness	OSR	0.09	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	19.47	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	19.71	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	453.79		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	21.30		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	4.00	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	3.77	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	74.07	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	74.97	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	3.50	m/m	h/dm
Average urban canyon main	Ucs	3.72	m/m	h/ds
Passive Zone	PZ	147,977	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.85	m^2/m^2	PZ/GFA
Model floor height	fh'	3.51	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

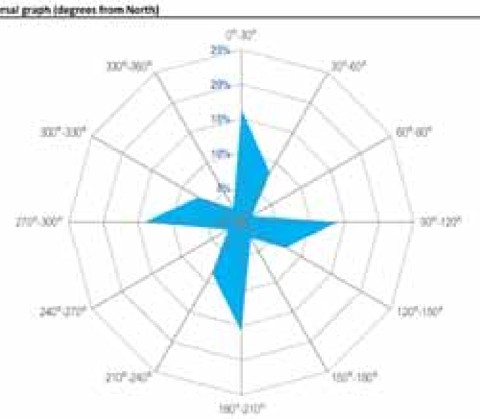


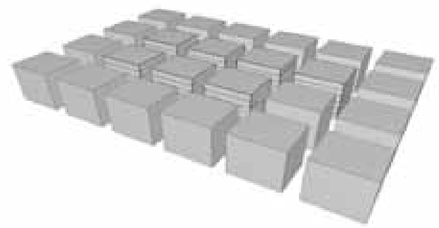


MAD GOYA

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	133,341	m^2	GIS
Built up area total	TFA	851,299	m^2	GIS
Envelope's area	Env	672,220	m^2	GIS
Volume	V	2,551,724	m^3	GIS
Orientation Ratio	Or	1.16	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	116,659	m^2	At-GFA
Perimeter	P	28,135	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	15,089	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	13,046	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.79	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.53	m^2/m^2	GFA/At
Floor Space Index	FSI	3.41	m^2/m^2	TFA/At
Building height avg	L	6.38	storeys	FSI/GSI
Height average	h	19.15	m	L*fh
Spaciousness	OSR	0.14	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	20.44	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	17.67	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	369.08		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	19.21		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	5.58	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	8.35	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	73.75	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	66.44	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	3.43	m/m	h/dm
Average urban canyon main	Ucs	2.29	m/m	h/ds
Passive Zone	PZ	115,664	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.87	m^2/m^2	PZ/GFA
Model floor height	fh'	3.19	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

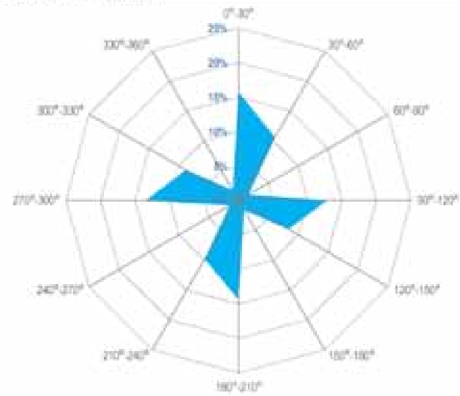


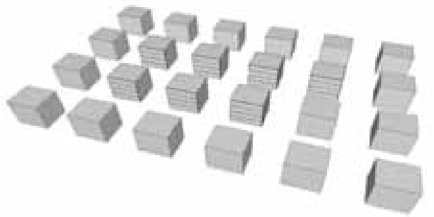


MAD PINAR DEL REY

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	53,165	m^2	GIS
Built up area total	TFA	253,024	m^2	GIS
Envelope's area	Env	272,193	m^2	GIS
Volume	V	757,796	m^3	GIS
Orientation Ratio	Or	1.16	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	196,835	m^2	At-GFA
Perimeter	P	15,341	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	8,223	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	7,117	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.08	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.21	m^2/m^2	GFA/At
Floor Space Index	FSI	1.01	m^2/m^2	TFA/At
Building height avg	L	4.76	storeys	FSI/GSI
Height average	h	14.28	m	L*fh
Spaciousness	OSR	0.78	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	14.94	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	12.93	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	275.22		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	16.59		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	**dm**	**15.20**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**17.21**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	43.21	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	39.68	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.94	m/m	h/dm
Average urban canyon main	Ucs	0.83	m/m	h/ds
Passive Zone	PZ	52,413	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.99	m^2/m^2	PZ/GFA
Model floor height	fh'	3.57	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

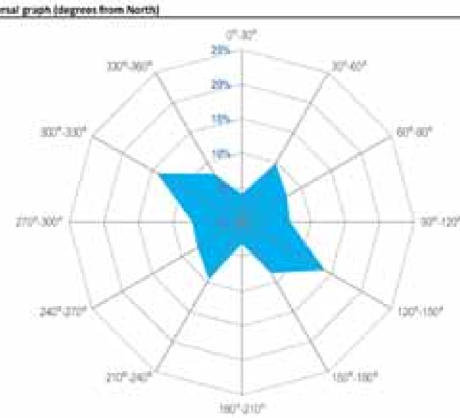


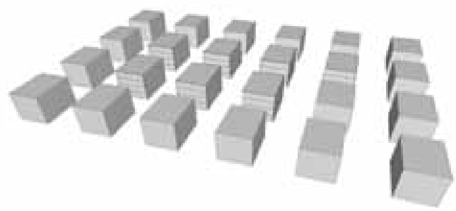


MAD SIMANCAS

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	73,605	m^2	GIS
Built up area total	TFA	307,098	m^2	GIS
Envelope's area	Env	352,630	m^2	GIS
Volume	V	920,109	m^3	GIS
Orientation Ratio	Or	0.75	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	176,395	m^2	At-GFA
Perimeter	P	22,292	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	9,584	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	12,708	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.15	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.29	m^2/m^2	GFA/At
Floor Space Index	FSI	1.23	m^2/m^2	TFA/At
Building height avg	L	4.17	storeys	FSI/GSI
Height average	h	12.52	m	L*fh
Spaciousness	OSR	0.57	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	11.58	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	15.36	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	413.68		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	20.34		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	**dm**	**13.00**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**9.22**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	43.92	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	53.61	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.96	m/m	h/dm
Average urban canyon main	Ucs	1.36	m/m	h/ds
Passive Zone	PZ	74,183	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	1.01	m^2/m^2	PZ/GFA
Model floor height	fh'	3.13	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

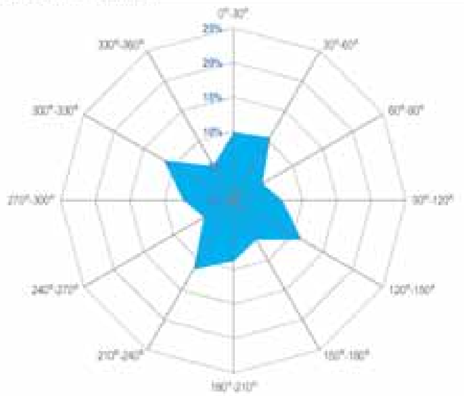


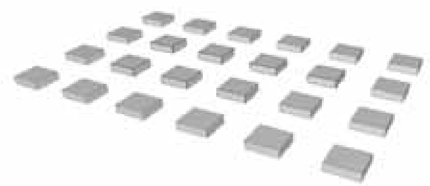


MAD PIOVERA

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	48,676	m²	GIS
Built up area total	TFA	76,517	m²	GIS
Envelope's area	Env	112,857	m²	GIS
Volume	V	229,235	m³	GIS
Orientation Ratio	Or	1.13	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	201,324	m²	At-GFA
Perimeter	P	13,610	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	7,217	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	6,393	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.47	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.19	m²/m²	GFA/At
Floor Space Index	FSI	0.31	m²/m²	TFA/At
Building height avg	L	1.57	storeys	FSI/GSI
Height average	h	4.72	m	L*fh
Spaciousness	OSR	2.63	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	15.23	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	13.49	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	236.95		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	15.39		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	**dm**	**17.25**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**18.99**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	15.29	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	13.94	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.27	m/m	h/dm
Average urban canyon main	Ucs	0.25	m/m	h/ds
Passive Zone	PZ	47,537	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.98	m²/m²	PZ/GFA
Model floor height	fh'	4.72	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

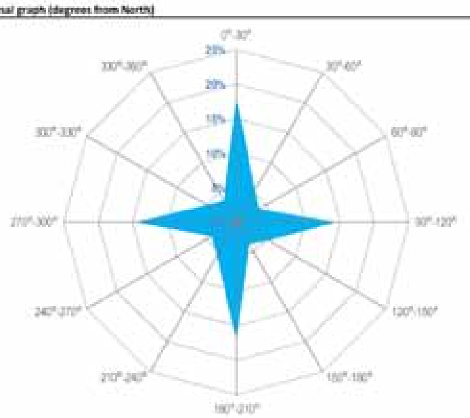




MAD VALDEMARÍN

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	16,579	m²	GIS
Built up area total	TFA	28,534	m²	GIS
Envelope's area	Env	38,388	m²	GIS
Volume	V	85,191	m³	GIS
Orientation Ratio	Or	1.13	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	233,421	m²	At-GFA
Perimeter	P	4,224	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	2,236	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	1,987	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.35	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.07	m²/m²	GFA/At
Floor Space Index	FSI	0.11	m²/m²	TFA/At
Building height avg	L	1.72	storeys	FSI/GSI
Height average	h	5.16	m	L*fh
Spaciousness	OSR	8.18	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	16.68	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	14.83	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	67.02		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	8.19		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	**dm**	**44.39**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**46.25**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	6.63	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	6.37	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.12	m/m	h/dm
Average urban canyon main	Ucs	0.11	m/m	h/ds
Passive Zone	PZ	15,692	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.95	m²/m²	PZ/GFA
Model floor height	fh'	5.16	m	fh'= h/integer (L)

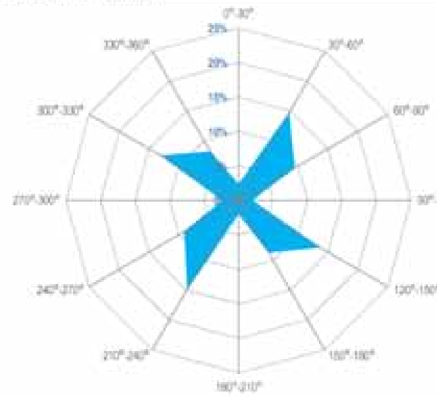
Orientation dispersal graph (degrees from North)

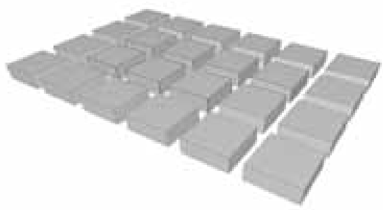


LONDON MAYFAIR

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	149,020	m^2	GIS
Built up area total	TFA	713,807	m^2	GIS
Envelope's area	Env	400,075	m^2	GIS
Volume	V	2,139,273	m^3	GIS
Orientation Ratio	Or	1.03	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	100,980	m^2	At-GFA
Perimeter	P	17,471	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	8,874	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	8,597	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.56	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.60	m^2/m^2	GFA/At
Floor Space Index	FSI	2.86	m^2/m^2	TFA/At
Building height avg	L	4.79	storeys	FSI/GSI
Height average	h	14.37	m	L*fh
Spaciousness	OSR	0.14	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	34.67	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	33.59	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	127.96		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	11.31		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	9.53	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	10.61	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	56.45	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	53.56	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	1.51	m/m	h/dm
Average urban canyon main	Ucs	1.35	m/m	h/ds
Passive Zone	PZ	86,395	m^2	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.58	m^2/m^2	PZ/GFA
Model floor height	fh'	3.59	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

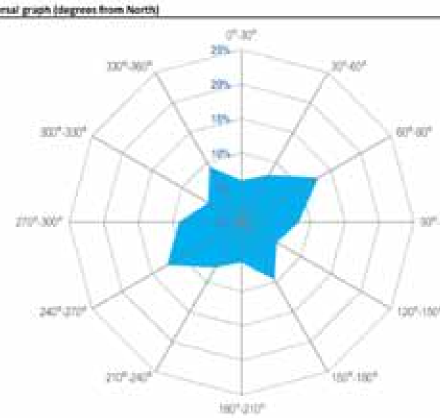


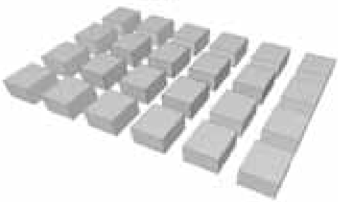


LONDON MARYLEBONE

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	115,116	m^2	GIS
Built up area total	TFA	576,513	m^2	GIS
Envelope's area	Env	421,423	m^2	GIS
Volume	V	1,733,273	m^3	GIS
Orientation Ratio	Or	0.85	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	134,884	m^2	At-GFA
Perimeter	P	20,387	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	9,378	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	11,010	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.73	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.46	m^2/m^2	GFA/At
Floor Space Index	FSI	2.31	m^2/m^2	TFA/At
Building height avg	L	5.01	storeys	FSI/GSI
Height average	h	15.02	m	L*fh
Spaciousness	OSR	0.23	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	20.91	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	24.55	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	224.22		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	14.97		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	12.48	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	8.84	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	50.29	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	59.53	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	1.20	m/m	h/dm
Average urban canyon main	Ucs	1.70	m/m	h/ds
Passive Zone	PZ	90,037	m^2	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.78	m^2/m^2	PZ/GFA
Model floor height	fh'	3.00	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

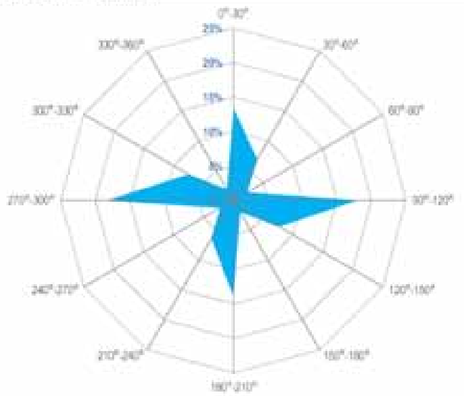


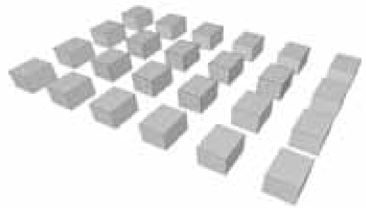


Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side	a	500	m	500m
Built footprint	GFA	64,080	m²	GIS
Built up area total	TFA	286,495	m²	GIS
Envelope's area	Env	275,831	m²	GIS
Volume	V	855,981	m³	GIS
Orientation Ratio	Or	0.79	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	185,920	m²	At-GFA
Perimeter	P	15,787	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	6,977	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	8,810	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.96	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.26	m²/m²	GFA/At
Floor Space Index	FSI	1.15	m²/m²	TFA/At
Building height avg	L	4.47	storeys	FSI/GSI
Height average	h	13.41	m	L*fh
Spaciousness	OSR	0.65	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	14.55	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	18.37	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	239.82		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	15.49		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	**dm**	**17.74**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**13.92**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	37.09	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	43.94	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.76	m/m	h/dm
Average urban canyon main	Ucs	0.96	m/m	h/ds
Passive Zone	PZ	60,190	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.94	m²/m²	PZ/GFA
Model floor height	fh'	3.35	m	fh'= h/integer (L)

LONDON REGENTS PARK STATE

Orientation dispersal graph (degrees from North)

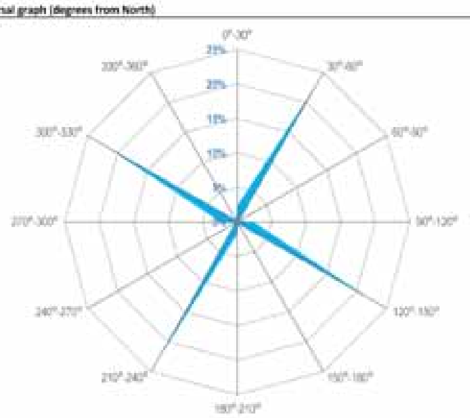


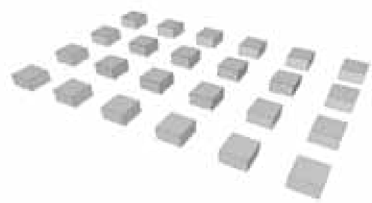


Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	42,674	m²	GIS
Built up area total	TFA	146,337	m²	GIS
Envelope's area	Env	146,973	m²	GIS
Volume	V	435,993	m³	GIS
Orientation Ratio	Or	1.01	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	207,326	m²	At-GFA
Perimeter	P	10,138	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	5,105	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	5,033	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.00	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.17	m²/m²	GFA/At
Floor Space Index	FSI	0.59	m²/m²	TFA/At
Building height avg	L	3.43	storeys	FSI/GSI
Height average	h	10.29	m	L*fh
Spaciousness	OSR	1.42	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	16.96	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	16.72	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	150.53		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	12.27		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	**dm**	**23.80**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**24.03**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	23.38	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	23.17	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.43	m/m	h/dm
Average urban canyon main	Ucs	0.43	m/m	h/ds
Passive Zone	PZ	39,158	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.92	m²/m²	PZ/GFA
Model floor height	fh'	3.43	m	fh'= h/integer (L)

LONDON PUTNEY

Orientation dispersal graph (degrees from North)

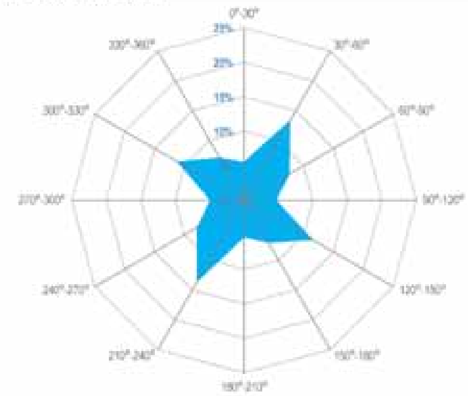


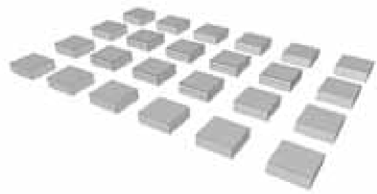


Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	72,536	m^2	GIS
Built up area total	TFA	201,798	m^2	GIS
Envelope's area	Env	189,948	m^2	GIS
Volume	V	580,122	m^3	GIS
Orientation Ratio	Or	1.09	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	OS	177,464	m^2	At-GFA
Perimeter	P	14,068	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	7,337	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	6,730	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.94	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.29	m^2/m^2	GFA/At
Floor Space Index	FSI	0.81	m^2/m^2	TFA/At
Building height avg	L	2.78	storeys	FSI/GSI
Height average	h	8.35	m	L*fh
Spaciousness	OSR	0.88	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	21.55	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	19.77	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	170.21		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	13.05		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	16.77	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	18.55	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	26.46	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	24.22	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.50	m/m	h/dm
Average urban canyon main	Ucs	0.45	m/m	h/ds
Passive Zone	PZ	59,898	m^2	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.83	m^2/m^2	PZ/GFA
Model floor height	fh'	4.17	m	fh'= h/integer (L)

LONDON WEMBLEY

Orientation dispersal graph (degrees from North)

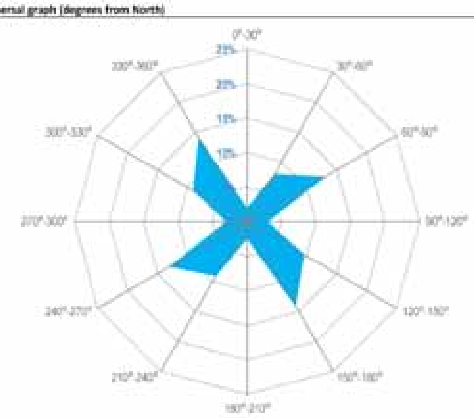


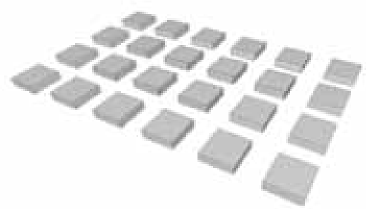


Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	85,253	m^2	GIS
Built up area total	TFA	206,771	m^2	GIS
Envelope's area	Env	197,608	m^2	GIS
Volume	V	620,813	m^3	GIS
Orientation Ratio	Or	0.98	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	OS	164,747	m^2	At-GFA
Perimeter	P	15,450	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	7,648	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	7,802	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.96	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.34	m^2/m^2	GFA/At
Floor Space Index	FSI	0.83	m^2/m^2	TFA/At
Building height avg	L	2.43	storeys	FSI/GSI
Height average	h	7.28	m	L*fh
Spaciousness	OSR	0.80	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	21.85	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	22.30	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	174.97		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	13.23		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	15.95	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	15.50	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	24.53	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	25.14	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.46	m/m	h/dm
Average urban canyon main	Ucs	0.47	m/m	h/ds
Passive Zone	PZ	67,503	m^2	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.79	m^2/m^2	PZ/GFA
Model floor height	fh'	3.64	m	fh'= h/integer (L)

LONDON KILBURN

Orientation dispersal graph (degrees from North)

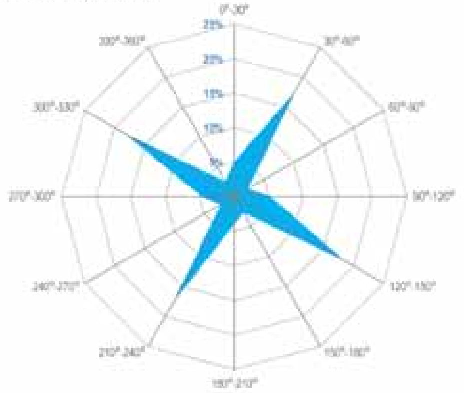


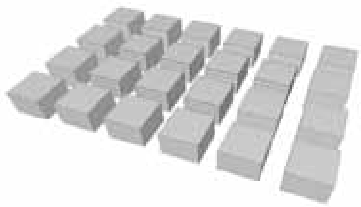


Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	126,485	m²	GIS
Built up area total	TFA	513,483	m²	GIS
Envelope's area	Env	520,383	m²	GIS
Volume	V	1,538,749	m³	GIS
Orientation Ratio	Or	0.96	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	123,515	m²	At-GFA
Perimeter	P	32,343	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	15,838	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	16,505	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.01	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.51	m²/m²	GFA/At
Floor Space Index	FSI	2.05	m²/m²	TFA/At
Building height avg	L	4.06	storeys	FSI/GSI
Height average	h	12.18	m	L*fh
Spaciousness	OSR	0.24	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	15.33	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	15.97	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	516.66		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	22.73		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	6.67	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	6.02	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	61.29	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	63.68	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	1.83	m/m	h/dm
Average urban canyon main	Ucs	2.02	m/m	h/ds
Passive Zone	PZ	119,657	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.95	m²/m²	PZ/GFA
Model floor height	fh'	3.04	m	fh'= h/integer (L)

PARIS 3RD ARRONDISSEMENT

Orientation dispersal graph (degrees from North)

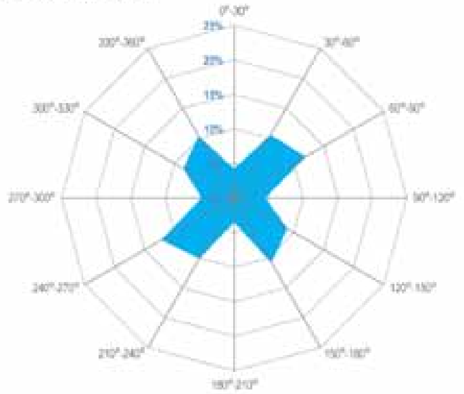


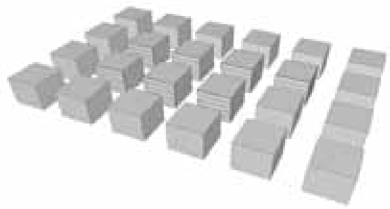


Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	91,485	m²	GIS
Built up area total	TFA	473,795	m²	GIS
Envelope's area	Env	441,053	m²	GIS
Volume	V	1,419,541	m³	GIS
Orientation Ratio	Or	0.98	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	158,515	m²	At-GFA
Perimeter	P	22,499	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	11,118	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	11,381	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.93	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.37	m²/m²	GFA/At
Floor Space Index	FSI	1.90	m²/m²	TFA/At
Building height avg	L	5.18	storeys	FSI/GSI
Height average	h	15.54	m	L*fh
Spaciousness	OSR	0.33	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	16.08	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	16.46	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	345.79		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	18.60		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	10.81	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	10.43	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	55.17	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	56.12	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	1.44	m/m	h/dm
Average urban canyon main	Ucs	1.49	m/m	h/ds
Passive Zone	PZ	85,202	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.93	m²/m²	PZ/GFA
Model floor height	fh'	3.11	m	fh'= h/integer (L)

PARIS 11TH ARRONDISSEMENT

Orientation dispersal graph (degrees from North)

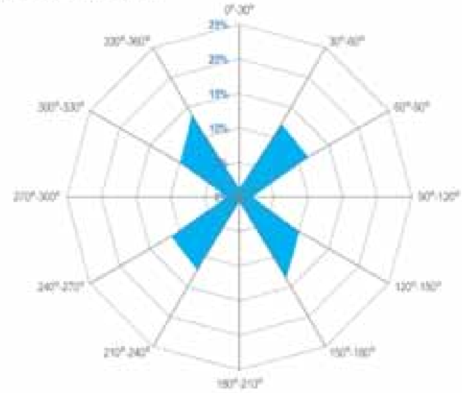


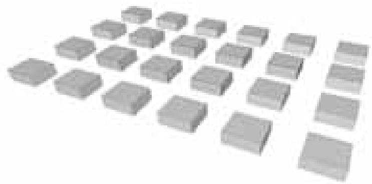


Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	66,523	m^2	GIS
Built up area total	TFA	225,949	m^2	GIS
Envelope's area	Env	195,563	m^2	GIS
Volume	V	676,636	m^3	GIS
Orientation Ratio	Or	1.15	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	183,477	m^2	At-GFA
Perimeter	P	12,664	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	6,778	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	5,886	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.87	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.27	m^2/m^2	GFA/At
Floor Space Index	FSI	0.90	m^2/m^2	TFA/At
Building height avg	L	3.40	storeys	FSI/GSI
Height average	h	10.19	m	L*fh
Spaciousness	OSR	0.81	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	22.61	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	19.63	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	149.92		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	12.24		nr=root (P^2*Or /(4GFA*(1+Or)^2))
Average distance Main axis	**dm**	**18.23**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**21.21**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	29.20	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	25.66	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.56	m/m	h/dm
Average urban canyon main	Ucs	0.48	m/m	h/ds
Passive Zone	PZ	54,394	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.82	m^2/m^2	PZ/GFA
Model floor height	fh'	3.40	m	fh'= h/integer (L)

PARIS 13TH ARRONDISSEMENT

Orientation dispersal graph (degrees from North)

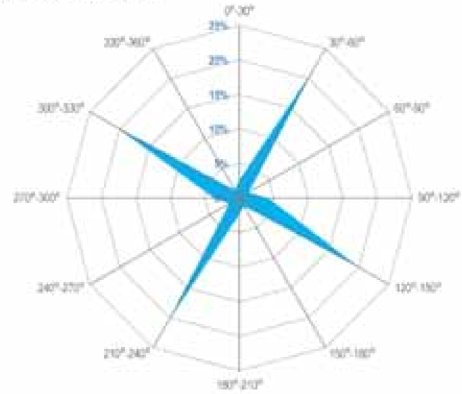


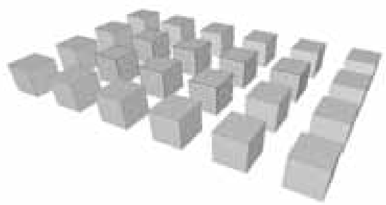


Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	69,335	m^2	GIS
Built up area total	TFA	511,125	m^2	GIS
Envelope's area	Env	388,205	m^2	GIS
Volume	V	1,533,375	m^3	GIS
Orientation Ratio	Or	0.95	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	180,665	m^2	At-GFA
Perimeter	P	14,418	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	7,013	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	7,406	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.76	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.28	m^2/m^2	GFA/At
Floor Space Index	FSI	2.04	m^2/m^2	TFA/At
Building height avg	L	7.37	storeys	FSI/GSI
Height average	h	22.12	m	L*fh
Spaciousness	OSR	0.35	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	18.72	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	19.77	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	187.26		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	13.68		nr=root (P^2*Or /(4GFA*(1+Or)^2))
Average distance Main axis	**dm**	**17.81**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**16.76**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	51.15	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	52.84	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	1.24	m/m	h/dm
Average urban canyon main	Ucs	1.32	m/m	h/ds
Passive Zone	PZ	59,545	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.86	m^2/m^2	PZ/GFA
Model floor height	fh'	3.16	m	fh'= h/integer (L)

PARIS LA VILLETTE

Orientation dispersal graph (degrees from North)

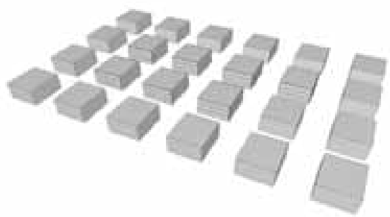




Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	80,378	m^2	GIS
Built up area total	TFA	246,268	m^2	GIS
Envelope's area	Env	274,287	m^2	GIS
Volume	V	737,219	m^3	GIS
Orientation Ratio	Or	0.92	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	169,622	m^2	At-GFA
Perimeter	P	21,096	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	10,098	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	10,998	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.11	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.32	m^2/m^2	GFA/At
Floor Space Index	FSI	0.99	m^2/m^2	TFA/At
Building height avg	L	3.06	storeys	FSI/GSI
Height average	h	9.19	m	L*fh
Spaciousness	OSR	0.69	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	14.62	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	15.92	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	345.43		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	18.59		nr=root (P^2*Or /(4GFA*(1+Or)^2))
Average distance Main axis	dm	12.29	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	10.98	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	36.80	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	39.93	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.75	m/m	h/dm
Average urban canyon main	Ucs	0.84	m/m	h/ds
Passive Zone	PZ	76,836	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.96	m^2/m^2	PZ/GFA
Model floor height	fh'	3.06	m	fh'= h/integer (L)

PARIS AMÉRIQUE

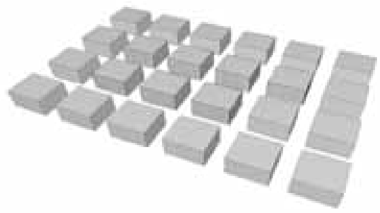
Orientation dispersal graph (degrees from North)



Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m^2	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	103,190	m^2	GIS
Built up area total	TFA	511,299	m^2	GIS
Envelope's area	Env	355,289	m^2	GIS
Volume	V	1,534,248	m^3	GIS
Orientation Ratio	Or	1.16	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	146,810	m^2	At-GFA
Perimeter	P	16,959	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	9,105	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	7,854	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.69	m^2/m^2	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.41	m^2/m^2	GFA/At
Floor Space Index	FSI	2.05	m^2/m^2	TFA/At
Building height avg	L	4.95	storeys	FSI/GSI
Height average	h	14.86	m	L*fh
Spaciousness	OSR	0.29	m^2/m^2	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	26.28	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	22.67	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	173.26		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	13.16		nr=root (P^2*Or /(4GFA*(1+Or)^2))
Average distance Main axis	dm	11.71	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	15.32	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	51.77	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	44.14	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	1.27	m/m	h/dm
Average urban canyon main	Ucs	0.97	m/m	h/ds
Passive Zone	PZ	76,808	m^2	PZ=P*2fh-2fh^2*4*Nt
Ratio Passive/nonPassive	PZr	0.74	m^2/m^2	PZ/GFA
Model floor height	fh'	3.72	m	fh'= h/integer (L)

BERLIN HERRFURTHPLATZ

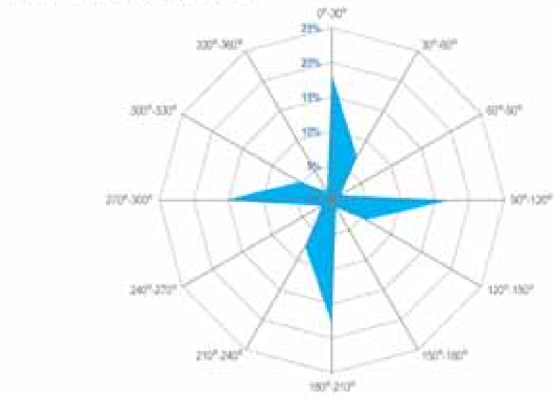
Orientation dispersal graph (degrees from North)

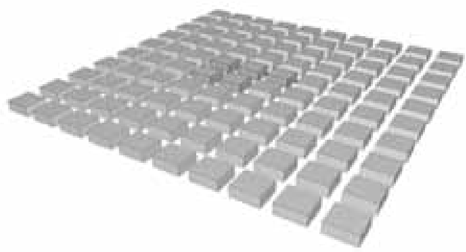


BERLIN CHARLOTTENBURG

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	113,065	m²	GIS
Built up area total	TFA	586,910	m²	GIS
Envelope's area	Env	335,354	m²	GIS
Volume	V	1,759,704	m³	GIS
Orientation Ratio	Or	1.15	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	136,935	m²	At-GFA
Perimeter	P	14,274	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	7,644	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	6,630	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.57	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.45	m²/m²	GFA/At
Floor Space Index	FSI	2.35	m²/m²	TFA/At
Building height avg	L	5.19	storeys	FSI/GSI
Height average	h	15.57	m	L*fh
Spaciousness	OSR	0.23	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	34.11	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	29.58	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	112.06		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	10.59		nr=root (P^2*Or /(4GFA*(1+Or)^2))
Average distance Main axis	**dm**	**13.13**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**17.65**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	49.87	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	41.42	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	1.19	m/m	h/dm
Average urban canyon main	Ucs	0.88	m/m	h/ds
Passive Zone	PZ	69,508	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.61	m²/m²	PZ/GFA
Model floor height	fh'	3.11	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

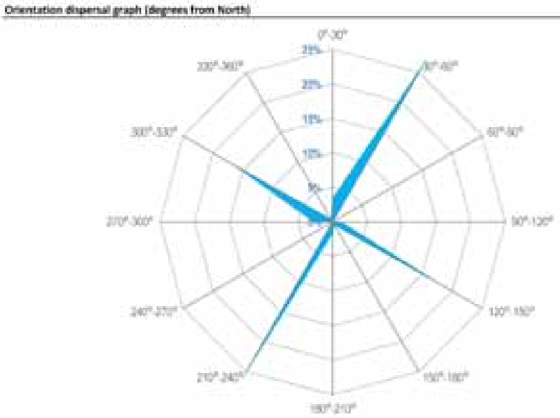


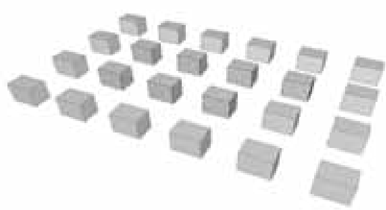


BERLIN SCHILLINGSTRASSE

Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	36,319	m²	GIS
Built up area total	TFA	267,690	m²	GIS
Envelope's area	Env	185,315	m²	GIS
Volume	V	802,662	m³	GIS
Orientation Ratio	Or	1.48	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	213,681	m²	At-GFA
Perimeter	P	6,738	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	4,017	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	2,721	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	0.69	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.15	m²/m²	GFA/At
Floor Space Index	FSI	1.07	m²/m²	TFA/At
Building height avg	L	7.37	storeys	FSI/GSI
Height average	h	22.11	m	L*fh
Spaciousness	OSR	0.80	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	26.70	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	18.08	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	75.24		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	8.67		nr=root (P^2*Or /(4GFA*(1+Or)^2))
Average distance Main axis	**dm**	**30.95**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	**ds**	**39.56**	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	**θm**	35.55	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	**θm**	29.20	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.71	m/m	h/dm
Average urban canyon main	Ucs	0.56	m/m	h/ds
Passive Zone	PZ	29,595	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.81	m²/m²	PZ/GFA
Model floor height	fh'	3.16	m	fh'= h/integer (L)

Orientation dispersal graph (degrees from North)

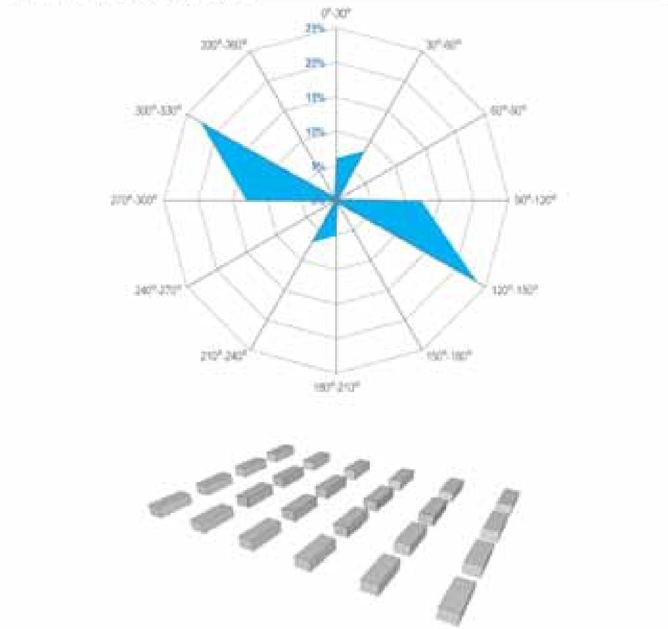




Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	41,512	m²	GIS
Built up area total	TFA	138,039	m²	GIS
Envelope's area	Env	138,269	m²	GIS
Volume	V	433,455	m³	GIS
Orientation Ratio	Or	0.38	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	208,488	m²	At-GFA
Perimeter	P	9,699	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	2,677	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	7,022	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.00	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.17	m²/m²	GFA/At
Floor Space Index	FSI	0.55	m²/m²	TFA/At
Building height avg	L	3.33	storeys	FSI/GSI
Height average	h	9.98	m	L*fh
Spaciousness	OSR	1.51	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	11.82	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	31.01	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	113.72		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	10.66		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	35.17	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	15.98	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	15.84	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	31.97	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.28	m/m	h/dm
Average urban canyon main	Ucs	0.62	m/m	h/ds
Passive Zone	PZ	41,891	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	1.01	m²/m²	PZ/GFA
Model floor height	fh'	3.33	m	fh'= h/integer (L)

BERLIN GIELOWER STRASSE

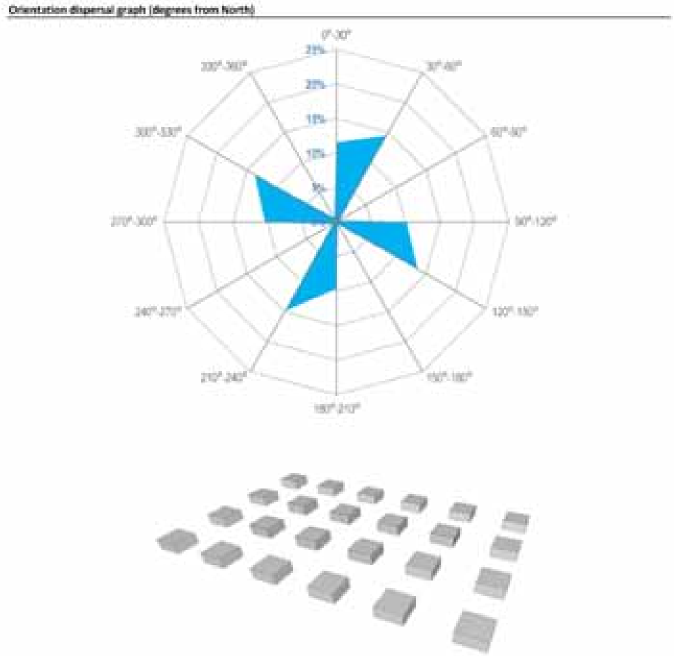
Orientation dispersal graph (degrees from North)



Concept	Acronym	Result	Units	Origin
Inputs				
Sample Total area	At	250,000	m²	500x500m
Sample side length	a	500	m	500m
Ground Floor Area	GFA	40,352	m²	GIS
Built up area total	TFA	119,889	m²	GIS
Envelope's area	Env	125,192	m²	GIS
Volume	V	359,845	m³	GIS
Orientation Ratio	Or	1.05	m/m	GIS
Typical Floor height	fh	3	m	Input
Derived Parameters				
Open Space	Os	209,648	m²	At-GFA
Perimeter	P	9,518	m	P= (Env-GFA)/h
Perimeter Main axis	Pm	4,885	m	Pm=Ps*Or
Perimeter Secondary axis	Ps	4,634	m	Ps=P/(1+Or)
Exposed envelope/total floor area	Comp	1.04	m²/m²	Env/TFA
Spacemate Parameters				
Ground Space Index	GSI	0.16	m²/m²	GFA/At
Floor Space Index	FSI	0.48	m²/m²	TFA/At
Building height avg	L	2.97	storeys	FSI/GSI
Height average	h	8.91	m	L*fh
Spaciousness	OSR	1.75	m²/m²	(1-GSI)/FSI
Energy Model Mean values				
Module:				
Avg Length Main axis	bm	17.42	m	bm= GFA*2(1+Or)/P
Avg Length Secondary axis	bs	16.52	m	bs=GFA*2(1+Or)/P*Or
Number of elements	nt	140.23		nt=P^2*Or /(4GFA*(1+Or)^2
Elements per row/column	nr	11.84		nr=root (P^2*Or /(4GFA*(1+Or)^2)
Average distance Main axis	dm	24.81	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA)
Average distance Secondary axis	ds	25.70	m	dm=(2(1+Or)/P)*(a*(GFA/Or)^0.5-GFA/Or)
Average obstruction angle Main axis	θm	19.76	degrees	arctan (h/dm)*180/Pi
Average obstruction angle Secondary axis	θm	19.13	degrees	arctan (h/ds)*180/Pi
Average urban canyon main	Ucm	0.36	m/m	h/dm
Average urban canyon main	Ucs	0.35	m/m	h/ds
Passive Zone	PZ	36,917	m²	PZ=P*2fh-2fh²*4*Nt
Ratio Passive/nonPassive	PZr	0.91	m²/m²	PZ/GFA
Model floor height	fh'	4.46	m	fh'= h/integer (L)

BERLIN WESTEND

Orientation dispersal graph (degrees from North)



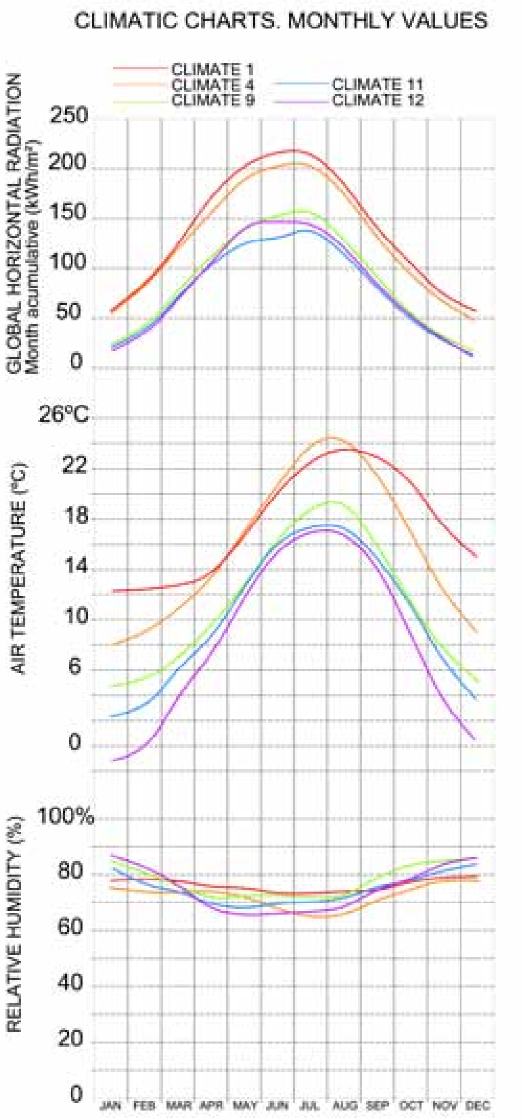
Data specification for Climatelite models

Table.App-3 Climatelite input data

CLIMATELITE INPUTS

	Retail	Industrial	Facilities	Office	Residential	
U-value Wall:	0.62	0.62	0.62	0.62	0.62	W/m²K
U-value Roof:	0.4	0.4	0.4	0.4	0.4	W/m²K
U-value Floor:	0.46	0.46	0.46	0.46	0.46	W/m²K
Useful Lighting Efficacy :	20	20	20	25	15	lm/W
Datum	750	200	300	300	150	Lux
Internal Heat Gains	30	15	15	30	5	W/m²
Thermal mass	1	1	1	1	1	Scale 1-3
Fresh air (power)	15	15	15	15	15	W/m²
Ventilation Rate	1	1.5	1	1	1	ACH
Day start time	8	0	8	8	6	
Day lenght	11	24	12	11	18	hours

Climatelite and Urban Energy Index Weather Data



Data specification for Urban Energy Index

Table.App-4 Construction type and thermal conductivity of building elements in the UEI model

	U-value
floor domestic retrofit	0.8
floor domestic reference	0.46
floor domestic standard	0.2
floor domestic low carbon	0.15
floor domestic zero carbon	0.15
floor non domestic retrofit	0.8
floor non domestic reference	0.46
floor non domestic standard	0.2
floor non domestic low carbon	0.15
floor non domestic zero carbon	0.1
wall domestic retrofit	1.5
wall domestic reference	0.62
wall domestic standard	0.3
wall domestic low carbon	0.2
wall domestic zero carbon	0.2
wall non domestic retrofit	1.5
wall non domestic reference	0.62
wall non domestic standard	0.25
wall non domestic low carbon	0.2
wall non domestic zero carbon	0.15
roof domestic retrofit	1.5
roof domestic reference	0.4
roof domestic standard	0.18
roof domestic low carbon	0.15
roof domestic zero carbon	0.15
roof non domestic retrofit	1.5
roof non domestic reference	0.4
roof non domestic standard	0.2
roof non domestic low carbon	0.15
roof non domestic zero carbon	0.1
window domestic retrofit	5.8
window domestic reference	2.9
window domestic standard	1.4
window domestic low carbon	0.8
window domestic zero carbon	0.6
window non domestic retrofit	5.8
window non domestic reference	2.9
window non domestic standard	1.4
window non domestic low carbon	0.8
window non domestic zero carbon	0.6

Table.App-5 Ventilation rate

	ACH
retail retrofit	2.25
retail reference	1
retail standard	1
retail low carbon	1
retail zero carbon	1
industrial retrofit	1.5
industrial reference	1
industrial standard	1
industrial low carbon	1
industrial zero carbon	1
facilities retrofit	2
facilities reference	1
facilities standard	1
facilities low carbon	1
facilities zero carbon	1
office retrofit	1.5
office reference	1
office standard	1
office low carbon	1
office zero carbon	1
domestic retrofit	1.5
domestic reference	1
domestic standard	1
domestic low carbon	1
domestic zero carbon	1

Table.App-6 Window transmittance

Window transmittance		0.8

Table.App-7 Albedo

	Albedo
Urban general	0.2
Clear	0.8
Dark	0.1

Table.App-8 Calendar: Occupied days per year

	Occupied days per year	
retail	260	
industrial	260	
facilities	190	
office	260	
domestic	365	

Table.App-9 Comfort Band

Comfort band	Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec
Optimal indoor temperature (Ti=0.33 Tm+18.8	18.40	18.67	19.69	20.37	21.77	22.79	23.32	23.32	22.45	21.09	19.69	19.01
Comfort band upper limit	20.90	21.17	22.19	22.87	24.27	25.29	25.82	25.82	24.95	23.59	22.19	21.51
Comfort band lower limit	15.90	16.17	17.19	17.87	19.27	20.29	20.82	20.82	19.95	18.59	17.19	16.51

Table.App-10 Lighting data

Surface reflectance		Lighting datum			Installed lighting density		
Floors	0.3	Residential	150	lux	Residential	10	w/m²
Walls	0.5	Office	300	lux	Office	12	w/m²
Ceilings	0.7	Facilities	300	lux	Facilities	15	w/m²
Windows	0.1	Retail	750	lux	Retail	38	w/m²
		Industrial	200	lux	Industrial	10	w/m²

Table.App-11 Other use of energy use (CIBSE Guide F. 20 Energy benchmarks)

Other use of energy (CIBSE Guide F. 20 Energy benchmarks) (kWh/m² year)	Equipment and other	Hot water	TOTAL
retail	36	26	62
industrial	46	5	51
facilities	25	43	68
office	30	6	36
domestic	10	35	45

Internal Heat Gains

(Data from table 4)

Internal Gains (W/m²)		Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec	
N days per month:		31	28	31	30	31	30	31	31	30	31	30	31	
Hour of day	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	6	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	7	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	8	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	9	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	10	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	11	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	12	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	13	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	14	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	15	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	16	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	17	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	18	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	19	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	20	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	21	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	22	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	23	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Day cumulative (wh/m²)		90	90	90	90	90	90	90	90	90	90	90	90	Year Total (kWh/m²)
Month cumulative (wh/m²)		2,790	2,520	2,790	2,700	2,790	2,700	2,790	2,790	2,700	2,790	2,700	2,790	32.85

Fig.App-14 Internal heat gains (residential)

Internal Heat Gains

(Data from table 4)

		Internal Gains (W/m²)												
Month:		Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec	
N days per month:		31	28	31	30	31	30	31	31	30	31	30	31	
Hour of day	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	8	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	9	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	10	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	11	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	12	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	13	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	14	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	15	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	16	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	17	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	18	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	
	19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Day cumulative (wh/m²)		275	275	275	275	275	275	275	275	275	275	275	275	Year Total (kWh/m²)
Month cumulative (wh/m²)		8,525	7,700	8,525	8,250	8,525	8,250	8,525	8,525	8,250	8,525	8,250	8,525	100.38

Fig.App-15 Internal heat gains (retail)

Internal Heat Gains

(Data from table 4)

		Internal Gains (W/m²)												
Month:		Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec	
N days per month:		31	28	31	30	31	30	31	31	30	31	30	31	
Hour of day	1	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	2	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	3	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	4	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	5	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	6	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	7	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	8	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	9	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	10	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	11	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	12	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	13	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	14	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	15	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	16	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	17	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	18	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	19	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	20	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	21	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	22	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	23	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
	24	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	
Day cumulative (wh/m²)		432	432	432	432	432	432	432	432	432	432	432	432	Year Total (kWh/m²)
Month cumulative (wh/m²)		13,392	12,096	13,392	12,960	13,392	12,960	13,392	13,392	12,960	13,392	12,960	13,392	157.68

Fig.App-16 Internal heat gains (industrial)

Internal Heat Gains

(Data from table 4)

		Internal Gains (W/m²)												
Month:		Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec	
N days per month:		31	28	31	30	31	30	31	31	30	31	30	31	
Hour of day	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	8	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	9	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	10	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	11	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	12	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	13	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	14	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	15	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	16	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	17	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	18	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	19	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Day cumulative (wh/m²)		180	180	180	180	180	180	180	180	180	180	180	180	Year Total (kWh/m²)
Month cumulative (wh/m²)		5,580	5,040	5,580	5,400	5,580	5,400	5,580	5,580	5,400	5,580	5,400	5,580	65.70

Fig.App-17 Internal heat gains (facilites)

Internal Heat Gains

(Data from table 4)

		Internal Gains (W/m²)												
Month:		Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec	
N days per month:		31	28	31	30	31	30	31	31	30	31	30	31	
Hour of day	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	8	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	9	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	10	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	11	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	12	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	13	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	14	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	15	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	16	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	17	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	18	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
	19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Day cumulative (wh/m²)		220	220	220	220	220	220	220	220	220	220	220	220	Year Total (kWh/m²)
Month cumulative (wh/m²)		6,820	6,160	6,820	6,600	6,820	6,600	6,820	6,820	6,600	6,820	6,600	6,820	80.30

Fig.App-18 Internal heat gains (office)

Chapter 7: The Formation of a Scattered City: London

Figs 7-2,7-13,7-18,7-24,7-29,7-36,7-41,7-44,7-48

OS MasterMap Topography Layer, supplied and licensed by EDINA Digimap Service:

- http://digimap.edina.ac.uk/digimap/home# [last visited 15.12.2013]

Processed and plotted in ArcGIS 10

Figs 7-1,7-8,7-12,7-17,7-23,7-28,7-35,7-40,7-43,7-47

Base map: DTM Land Form Panorama® supplied by Ordinance Survey Open Data

- https://www.ordnancesurvey.co.uk/opendatadownload/products.html [last visited 15.12.2013]

Historic urban areas were elaborated from digitized historic maps

20th century urban areas obtained from GMES Urban Atlas

- www.eea.europa.eu/data-and-maps/data/urban-atlas [last visited 15.12.2013]

Chapter 8: Densification in a Post-Industrial Scattered City: London Docklands

Figs. 8-18, 8-19,8-33,8-34,8-35,8-36,8-37

Land use maps for current state contain OS MasterMap Topography Layer as basic cartographic reference, supplied and licensed by EDINA Digimap Service as base map:

- http://digimap.edina.ac.uk/digimap/home# [last visited 15.12.2013]

Height and building use were checked with aerial imagery

Land use maps for 1981 state were digitized and redrawn from Ordinance Survey plans 1/10000 (1953-1981) HMSO. Height and building use were checked with aerial imagery and the Dockland History Survey:

- Carr, R.J.M. (1986) Dockland. An illustrated historical survey of life and work in east London. Thames & Hudson

Figs 8-50 to 8-52

Spatial analysis performed with the Urban Network Analysis tool:

- cityform.mit.edu/projects/urban-network-analysis.html [last visited 15.12.2013]

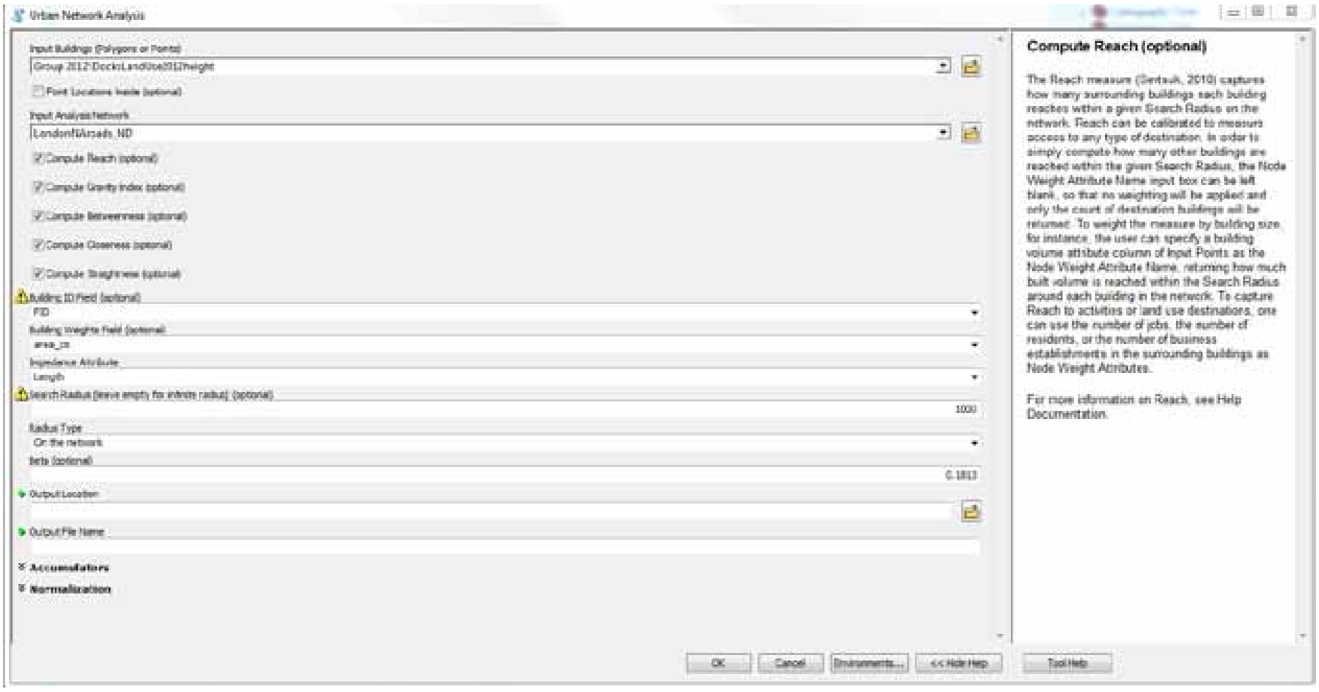


Fig. App-19 Urban Network Analysis Inputs

Chapter 9: A Compact City Paradigm: Barcelona

Figs 9-5, 9-8, 9-11, 9-14, 9-17, 9-20, 9-24, 9-30, 9-37, 9-43, 9-48,

Base map contains a DEM from SRTM, supplied by:

- Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. [last visited 15.12.2013]

Historic urban areas were elaborated from digitized historic maps

Figs 9-6, 9-9, 9-12, 9-15, 9-18, 9-21, 9-25, 9-31, 9-38, 9-44, 9-49

Maps contain cadastral data:

- “Cartografía catastral urbana digitalizada Barcelona actual”, available at www.sedecatastro.gob.es [last visited 15.12.2013]

Chapter 10: Densification in a Post-Industrial Compact City: From Poblenou to 22@

Figs, 10-37 to 10-42

Land use maps elaborated from cadastral data and checked with aerial photos to introduce building use and state in 1982:

- “Cartografía catastral urbana digitalizada Barcelona actual”, available at www.sedecatastro.gob.es [last visited 15.12.2013]
- “Cartografía catastral urbana digitalizada Barcelona histórica”, available at www.sedecatastro.gob.es [last visited 15.12.2013]

Figs 10-43 to 10-45

Spatial analysis performed with the Urban Network Analysis tool:

- cityform.mit.edu/projects/urban-network-analysis.html [last visited 15.12.2013]

Chapter 11: Comparative Analysis and Performance Assessment

Fig 11-2: London: Forms of urban growth and energy performance

OS MasterMap Topography Layer, supplied and licensed by EDINA Digimap Service:

- http://digimap.edina.ac.uk/digimap/home# [last visited 15.12.2013]

Base map: DTM Land Form Panorama® supplied by Ordinance Survey Open Data

- https://www.ordnancesurvey.co.uk/opendatadownload/products.html [last visited 15.12.2013]

Historic urban areas were elaborated from digitized historic maps

20th century urban areas obtained from GMES Urban Atlas

- www.eea.europa.eu/data-and-maps/data/urban-atlas [last visited 15.12.2013]

Energy assessment in UEI

Processed and plotted in ArcGIS 10

Fig 11-3: Barcelona: Forms of urban growth and energy performance

Base map contains a DEM from SRTM, supplied by:

- Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. [last visited 15.12.2013]

Historic urban areas were elaborated from digitized historic maps

Maps contain cadastral data:

- “Cartografía catastral urbana digitalizada Barcelona actual”, available at www.sedecatastro.gob.es [last visited 15.12.2013]

Energy assessment in UEI, processed and plotted in ArcGIS 10

Fig 11-7: Interpolated domestic heat load density at Poblenou before and after regeneration.

This map has been calculated by multiplying the average residential built up area by the average heat load per residential square meter for each cell of the raster map in UEI. A separate layer represents constructions: domestic buildings are in solid white whereas other building types are shown as semitransparent polygons. Barcelona's climate and default UEI values as indicated in chapter 6 have been used

Fig 11-8: Interpolated domestic heat load density at London Docklands before and after regeneration.

This map has been calculated by multiplying the average residential built up area by the average heat load per residential square meter for each cell of the raster map in UEI. A separate layer represents constructions: domestic buildings are in solid white whereas other building types are shown as semitransparent polygons. London's climate and default UEI values as indicated in chapter 6 have been used

11.4.3 Transport Calculations

Table.App-12 Average trip length calculations for Barcelona and its region, examples

Desplaçaments residència-treball. Distribució per mitjans de transport.
Municipi: Barcelona. 2001

	Working d.	Weekend/Tasks	
Total trips	6136412	3716228	
	Car	Moto	Train
Transport mode	8.166	3.859	

Avg Trip dist individual	Avg trip time individual	Avg trip speed individual	Nº of trips to BCN and BMR	internal trips	Trips to BCN	Other BMR	Other Catalunya
17.41531	22.40067	46.96374	57500	500843	0	57688	5720

	Mitjans de transport: només individual	només col·lectiu	individual i col·lectiu	a peu	altres mitjans	no es desplaça	no aplicable	Total	distancia	Time	speed km/h	trips*dist individual	trips*dist colect	Average trip dist (external) individual	colect	Trip*time individual	Avg trip time individual min	Avg trip speed individual km/h
Desplaçaments interns	186813	214158	16263	62436	18396	19684	2124	501903										
Hospitalet de Llobregat, l'	6440	5802	966	630	182	0	39	13759	0.6	18	28.66667	55304	49897.2	17.41531797	17.59627109		22.40067	46.96374
Badalona	4368	1951	248	18	57	0	28	6680	10.8	18	36	47174.4	21170.8			79624		
Prat de Llobregat, el	3646	2034	259	19	33	0	31	6321	11.3	18	37.66667	44678.5	22984.2			71016		
Cornellà de Llobregat	2660	1828	245	24	56	0	16	4829	16.5	18	61.66667	41230	28334			47880		
Sant Cugat del Vallès	2308	1811	241	7	29	0	31	4426	17.5	22	31.81818	42050	31692.5			70164		
Martorell	1460	2502	166	23	26	0	9	4176	30.2	36	66.51429	48146	83966.4			60750		
Sabadell	2289	1220	168	14	58	0	29	3726	26.2	21	68.70968	59736	21964			70668		
Esplugues de Llobregat	1799	1034	150	18	45	0	14	3022	8.7	18	29	15651.3	8734.8			32382		
Montcada i Reixac	2177	615	58	23	8	0	11	2932	13.2	26	30.46154	28736.4	8118			56602		
Cerdanyola del Vallès	1667	927	122	4	9	0	16	2645	16	24	40	26672	14832			37608		
Sant Joan Despí	1758	664	129	4	31	0	9	2595	12.8	20	41.4	20260.4	9163.2			35160		
Rubí	1739	642	108	7	17	0	9	2522	24.3	33	44.18182	42257.7	15600.6			57387		
Terrassa	1582	730	123	11	13	0	10	2405	28.0	32	53.625	45245.2	21100.8			50624		
Sant Boi de Llobregat	1714	623	58	9	58	0	9	2471	15.4	21	44	26395.6	9594.2			35994		
Santa Coloma de Gramenet	1173	1011	143	16	41	0	8	2392	9.5	17	33.52941	11143.5	9604.5			19941		
Santa Perpètua de Mogoda	1763	543	72	4	7	0	13	2389	21.4	29	44.27586	37514.2	11656			50817		
Sant Adrià de Besòs	1271	697	66	87	22	0	4	2251	7.8	17	27.52941	10053.8	5358.6			23307		
Sant Just Desvern	1639	482	73	6	31	0	17	2248	10.3	22	26.86967	16881.7	4964.6			37661		
Barberà del Vallès	1744	401	59	3	12	0	10	2229	18	25	43.2	31392	7218			43606		
Granollers	1387	634	56	6	11	0	19	2042	32.0	36	54.66667	42869.6	19811.2			47052		
Mollet del Vallès	961	610	58	1	5	0	10	1635	20.1	27	44.66667	19316.1	12261			25947		
Parets del Vallès	994	477	49	14	9	0	9	1562	30.3	30	60.6	30118.2	14453.1			29820		
Sant Feliu de Llobregat	927	435	81	5	15	0	2	1467	12	22	32.72727	11124	5256			20394		
Mataró	874	430	61	18	12	0	9	1424	30.9	33	56.18182	27006.6	14132.2			29842		
Sant Andreu de la Barca	998	353	46	15	8	0	8	1344	29.5	29	61.03448	26786	10090.5			26332		
Gavà	772	496	55	6	9	0	7	1344	21.4	28	61.36	16520.8	10593			19306		
Palau-solità i Plegamans	828	348	37	8	8	0	7	1234	30.4	34	53.64706	25171.2	10579.2			28152		
Viladecans	812	337	57	1	9	0	5	1221	10.3	23	49.30435	10346.8	6303.3			18676		
Molins de Rei	684	296	36	6	7	0	1	1014	17.8	23	46.43478	12176.2	5092.8			15732		
Ripollet	794	170	22	2	5	0	3	996	16.3	26	39.12	12942.2	2771			19868		

Desplaçaments residència-treball. Distribució per mitjans de transport.
Municipi: Montcada i Reixac. 2001

Avg Trip dist individual	Avg trip time individual	Avg trip speed individual	Nº of trips to BCN and BMR	Internal trips	Trips to Bcn	Other BMR	Other Catalunya
11.42466	19.70715	34.78327	3606	2088	1384	2222	771

	Mitjans de transport: només individual	només col·lectiu	individual i col·lectiu	a peu	altres mitjans	no es desplaça	no aplicable	Total	DIST	Time	speed km/h	trips*dist individual	collective	Avg Trip dist individual	collective	Trip*time individual	Avg trip time individual min	Avg trip speed individual km/h
Desplaçaments interns	2080	368	64	1602	20	233	46	4393										
Desplaçaments a altres m	4393	2150	267	22	44	0	997	7913						11.42466	12.67166		19.70715	34.78327
Barcelona	1384	1531	138	10	24	0	13	3100	13.1	23	34.17391	18130.4	20056.1			31832		
Ripollet	237	33	4	6	2	0	0	282	4.2	12	21	995.4	138.6			2844		
Cerdanyola del Vallès	203	56	5	0	3	0	0	271	4.9	11	26.72727	994.7	274.4			2233		
Sabadell	180	73	10	0	0	0	1	264	12	21	34.28571	2160	876			3780		
Barberà del Vallès	186	30	1	0	0	0	0	217	7.5	13	34.61538	1395	225			2418		
Santa Perpètua de Moged	193	8	4	1	2	0	1	209	7.3	18	24.33333	1408.9	58.4			3474		
Badalona	141	37	5	0	0	0	1	184	9.4	19	29.68421	1325.4	347.8			2679		
Mollet del Vallès	132	28	10	0	1	0	2	173	7.7	16	28.875	1016.4	215.6			2112		
Llagosta, la	105	19	3	2	2	0	1	132	4.1	10	24.6	430.5	77.9			1050		
Granollers	95	28	2	1	0	0	0	126	19.6	26	45.23077	1862	548.8			2470		
Sant Cugat del Vallès	97	22	5	0	0	0	1	125	11.3	25	27.12	1096.1	248.6			2425		
Palau-solità i Plegamans	98	9	1	0	1	0	0	109	17.5	22	47.72727	1715	157.5			2156		
Polinyà	98	11	0	0	0	0	0	109	15.6	23	40.69565	1528.8	171.6			2254		
Parets del Vallès	97	8	1	0	0	0	2	108	13.9	20	41.7	1348.3	111.2			1940		
Santa Coloma de Gramen	64	18	10	0	0	0	0	96	6.3	10	37.8	399.2	94.4			640		
Hospitalet de Llobregat, l'	51	29	7	0	0	0	2	89	20.4	27	45.33333	1040.4	591.6			1377		
Rubí	79	7	1	0	0	0	0	87	18.4	24	46	1453.6	128.8			1896		
Terrassa	63	15	3	0	0	0	0	81	20.7	20	62.1	1304.1	310.5			1260		
Sant Andreu de la Barca	46	20	4	0	0	0	0	70	25.9	31	50.12903	1191.4	518			1426		
Martorelles	57	8	1	0	0	0	0	66	8.1	14	34.71429	461.7	64.8			798		
Resta de Catalunya	771	191	48	2	0	0	13	1031										
Fora de Catalunya	16	9	0	0	0	0	27	52										
Desplaçaments a varis m	0	0	0	0	0	0	933	933										
Desplaçaments des d'altre	9191	1562	335	121	40	0	56	11305										
Barcelona	2177	615	98	23	8	0	11	2932										
Ripollet	759	57	21	20	1	0	3	861										
Cerdanyola del Vallès	727	89	18	4	10	0	1	849										
Badalona	745	78	20	0	0	0	2	845										
Santa Coloma de Gramen	559	93	16	1	4	0	1	674										
Mollet del Vallès	484	70	15	3	0	0	2	574										
Llagosta, la	332	59	5	61	0	0	2	459										
Sabadell	357	49	9	0	5	0	0	420										
Santa Perpètua de Moged	286	20	6	1	3	0	0	316										
Hospitalet de Llobregat, l'	154	65	25	2	0	0	0	246										
Terrassa	185	14	4	0	0	0	0	203										
Sant Cugat del Vallès	162	8	3	0	0	0	0	173										
Barberà del Vallès	125	12	3	0	0	0	0	140										
Cornellà de Llobregat	76	48	5	0	0	0	1	130										
Sant Adrià de Besòs	95	12	7	0	1	0	0	115										

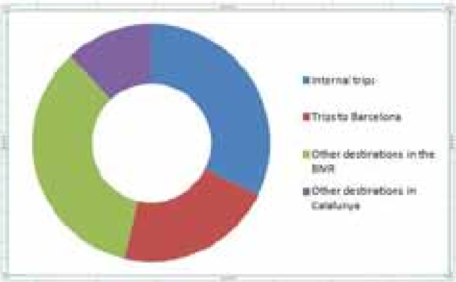


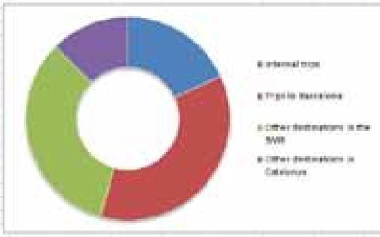
Table.App-13 Average trip length calculations for Barcelona and its region, examples

Desplaçaments residència-treball. Dist
Municipi: Sant Adrià de Besòs. 2001

Avg Trip d individual	Avg trip ti individual	Avg trip s individual	N° of trips to BCN and BMR	Internal trip	Trips to Bc	Other BMR	Other Catalunya
9.967392	16.84111	37.20192	5609	1613	2011	1047	696

	no es desplaça	no aplicable	Total	DIST	Time	speed km/h	trips*dist individual	collective	Avg Trip dist individual	collective	Trip*time individual	Avg trip ti individual min	Avg trip speed individual km/h
									9.967392	8.434897		16.84111	37.20192
Desplaçaments interns	123	34	3100										
Desplaçaments a altres municipis	0	1007	3680										
Barcelona	0	6	4027	7.4	15	29.6	14801.4	19106.8			30155		
Badalona	0	6	1214	3.5	10	21	2471	345			7890		
Santa Coloma de Gramenet	0	4	709	2.3	9	15.33333	342.2	156.6			1062		
Hospitalet de Llobregat, l'	0	6	768	17.5	26	43.39462	2362.5	437.6			3510		
Montcada i Reixac	0	6	116	7.9	17	27.88235	750.5	94.8			1615		
Prat de Llobregat, el	0	6	112	20	23	52.17391	1620	520			1863		
Mataró	0	6	99	39.2	34	69.17647	1097.6	2548			952		
Santa Perpètua de Mogoda	0	6	99	17.6	20	52.8	1320	352			1500		
Sant Andreu de la Barca	0	6	91	32.7	34	57.70588	2092.8	457.8			2176		
Granollers	0	6	88	27.2	27	60.44444	1740.8	326.4			1728		
Sabadell	0	6	73	18.8	20.6	54.75728	1052.8	206.8			1153.6		
Barberà del Vallès	0	6	70	14.3	16	53.625	915.2	42.9			1024		
Terrassa	0	6	67	27.5	23	71.73913	1567.5	192.5			1311		
Cornellà de Llobregat	0	6	61	22.7	23	59.21739	1157.7	113.5			1173		
Palau-solità i Plegamans	0	6	60	28.8	25	69.12	1215.2	288			1225		
Sant Cugat del Vallès	0	6	58	18.5	26	42.69231	735	277.5			988		
Rubí	0	6	55	26.6	28	55.07692	1152	202.8			1170		
Parets del Vallès	0	1	54	21.5	21	61.42857	800	236.5			840		
Cerdanyola del Vallès	0	6	52	12.2	15	48.8	512.4	73.2			630		
Mollet del Vallès	0	6	51	16.4	19	51.78947	639.6	164			741		
Resta de Catalunya	0	8	951										
Fora de Catalunya	0	47	83										
Desplaçaments a vaix municipis	0	541	541										
Desplaçaments des d'altres municipis	0	32	7429										
Badalona	0	3	2422										
Barcelona	0	4	2251										
Santa Coloma de Gramenet	0	1	767										
Hospitalet de Llobregat, l'	0	1	238										
Montgat	0	6	78										
Premià de Mar	0	6	69										
Cerdanyola del Vallès	0	6	68										
Masnou, el	0	6	56										
Cornellà de Llobregat	0	6	63										
Viladecans	0	6	61										
Montcada i Reixac	0	6	60										
Vilassar de Mar	0	1	57										
Prat de Llobregat, el	0	1	55										
Sant Boi de Llobregat	0	6	51										
Mataró	0	6	46										
Sabadell	0	6	43										

Internal trip	1613	Internal trip	1613
Trips to Bc	2011	Trips to Bc	2011
Other dest	1047	Other dest	1047
Other dest	696	Other dest	696



Desplaçaments residència-treball per...
Municipi: Santa Coloma de Gr...

Avg Trip d individual	Avg trip ti individual	Avg trip s individual	N° of trips to BCN and BMR	Internal trip	Trips to Bc	Other BMR	Other Catalunya
12.15893	17.77902	41.60664	12811	2329	5215	7306	3273

	a peu (…es de transport)	altres mitjans	no es desplaça	no aplicable	Total	DIST	Time	speed km/h	trips*dist individual	collective	Avg Trip dist individual	collective	Trip*time individual	Avg trip ti individual min	Avg trip speed individual km/h
											12.15893	11.12949		17.77902	41.60664
Desplaçaments interns	8864	44	722	188	12513										
Desplaçaments a altres municipis	814	135	0	4519	36326										
Barcelona	284	78	0	25	17834	13.1	18	43.67	57721.5	153075.5			102672		
Badalona	403	12	0	3	3290	4	10	24.00	7456	3085			10740		
Sant Adrià de Besòs	42	3	0	1	787	4	11	21.82	2180	832			5996		
Hospitalet de Llobregat, l'	8	2	0	3	737	17.1	25	41.04	9473.4	2086.2			13660		
Montcada i Reixac	1	4	0	1	674	5.3	11	28.91	2962.7	402.8			5743		
Martorell	1	1	0	0	592	30.8	32	69.88	6145.6	14504			5344		
Santa Perpètua de Mogoda	1	1	0	2	475	15.2	18	50.67	6716.2	1307.2			8768		
Granollers	1	2	0	2	412	24.8	25	59.52	7861.6	1711.2			7925		
Prat de Llobregat, el	1	0	0	0	411	20	26	50.77	6358	1514			7514		
Sabadell	0	0	0	1	354	18.2	20	54.60	5296.2	546			5820		
Sant Andreu de la Barca	20	2	0	0	346	31.5	32	59.06	8127	1984.5			8256		
Barberà del Vallès	0	1	0	0	330	11.8	15	47.20	3280.4	259.6			4170		
Parets del Vallès	0	0	0	1	290	19	19	60.00	4522	665			4522		
Montornès del Vallès	7	0	0	0	277	24.1	24	60.25	5495	2795.6			5472		
Mollet del Vallès	0	1	0	1	274	13.8	17	48.95	3868	466.5			3742		
Cornellà de Llobregat	2	0	0	2	274	22.4	24	56.00	4730.6	963.2			5136		
Sant Cugat del Vallès	3	0	0	0	274	19.5	23	50.87	3595	1054.5			4370		
Terrassa	0	0	0	1	250	25.1	21	71.71	6321.2	577.3			4452		
Rubí	3	2	0	1	230	22.8	24	57.00	3967.2	843.6			4176		
Palau-solità i Plegamans	2	3	0	1	225	22.4	23	58.43	4256	649.6			4370		
Resta de Catalunya	48	21	0	77	4305										
Fora de Catalunya	3	1	0	182	279										
Desplaçaments a vaix municipis	0	0	0	4219	4219										
Desplaçaments des d'altres municipis	427	55	0	72	6632										
Barcelona	18	41	0	3	2390										
Badalona	308	5	0	4	1831										
Sant Adrià de Besòs	22	0	0	4	130										
Hospitalet de Llobregat, l'	7	0	0	1	102										
Sant Fost de Campsentelles	1	0	0	0	97										
Montcada i Reixac	0	3	0	0	86										
Premià de Mar	0	0	0	1	83										
Mollet del Vallès	0	0	0	0	85										
Masnou, el	0	0	0	0	88										
Montgat	1	0	0	1	84										
Cerdanyola del Vallès	0	0	0	0	68										
Sabadell	0	0	0	0	67										
Cornellà de Llobregat	1	0	0	0	54										
Tiana	0	0	0	0	51										
Santa Perpètua de Mogoda	0	0	0	0	45										
Sant Cugat del Vallès	0	0	0	0	40										

Internal trip	2329
Trips to Bc	6715
Other dest	7306
Other dest	3273

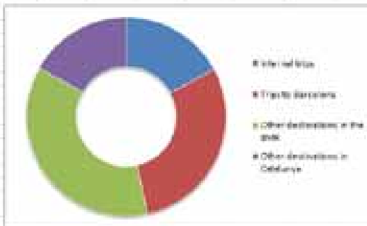
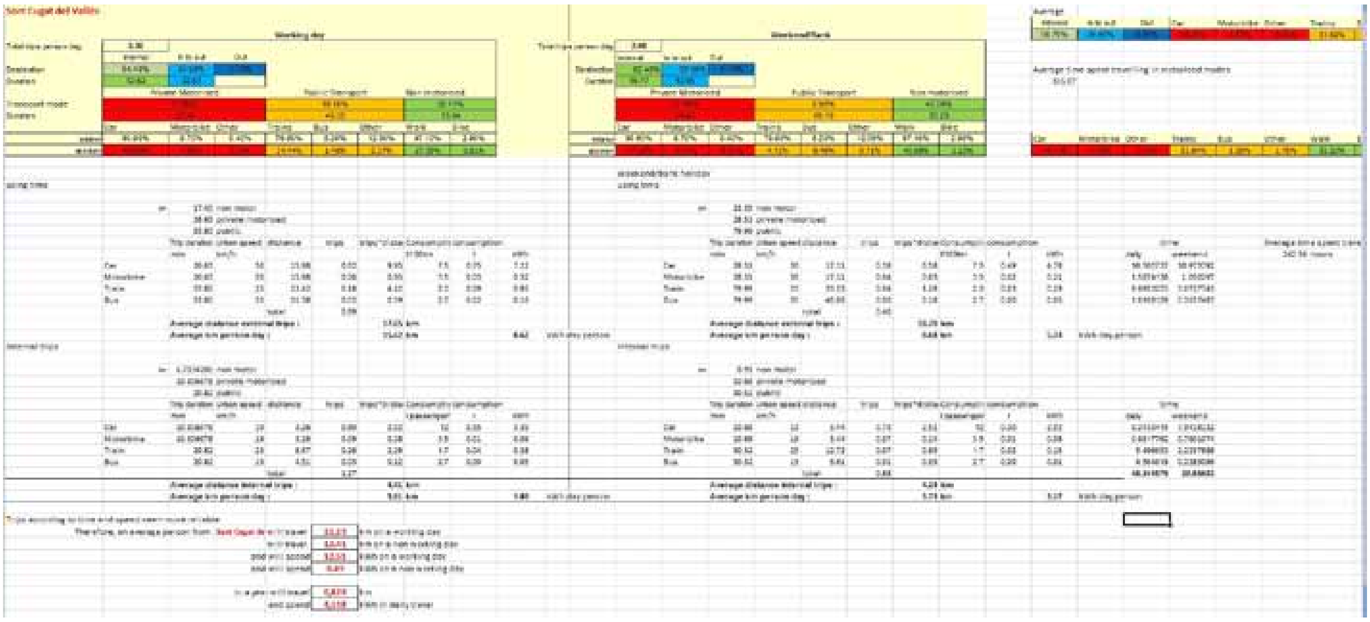


Table.App-14 Average trip length calculations for Barcelona and its region, examples



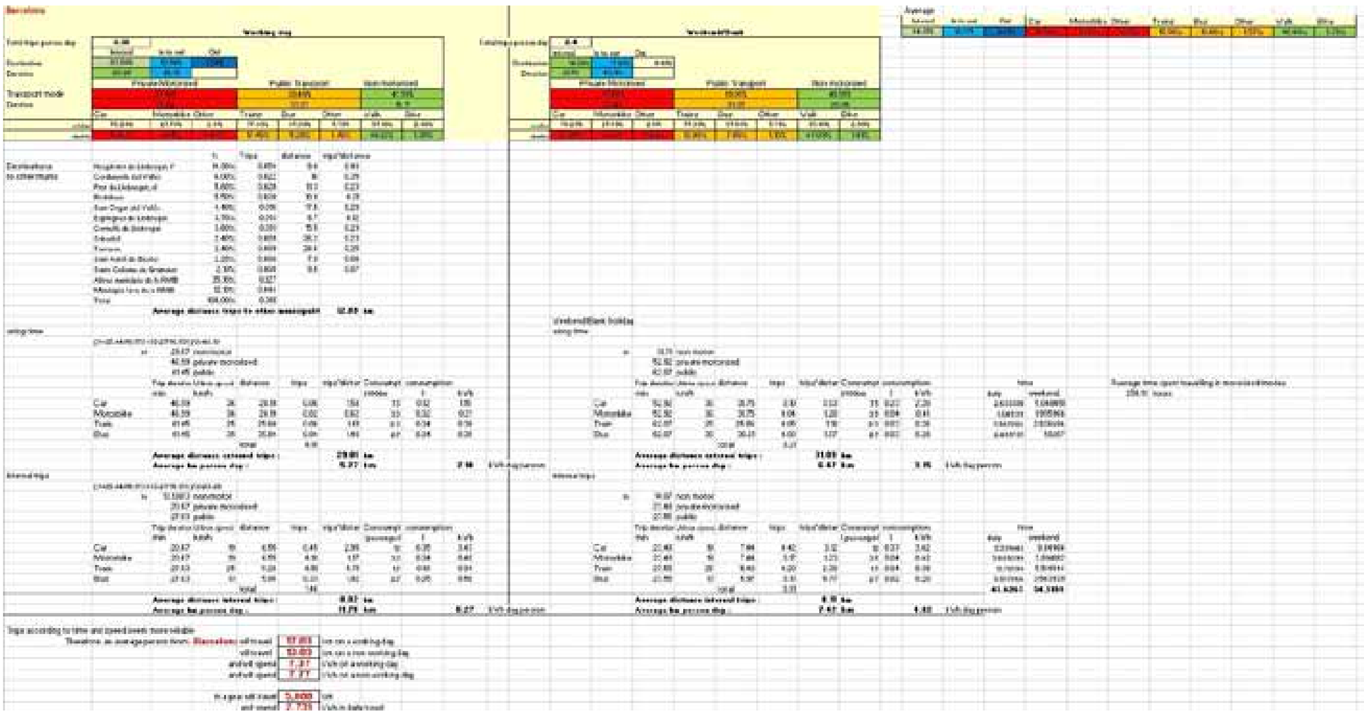


Table.App-15 Summary travel statistics for Barcelona and its region

	Area	Destinations			Transport Mode										
		Internal	In to out	Out	Car	Motorbike	Other	Private	Trains	Bus	Other	Public	Walk	Bike	Non motorised
Barcelona	0 BCN	84.55%	12.77%	2.61%	[illegible]	[illegible]	[illegible]	[illegible]	15.56%	10.06%	1.57%	27.19%	46.40%	1.39%	47.79%
Badalona	A1	62.79%	33.50%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.98%	5.70%	1.07%	16.76%	47.85%	1.43%	49.28%
Santa Coloma de Gramenet	A1	53.51%	41.44%	5.05%	[illegible]	[illegible]	[illegible]	[illegible]	11.16%	4.99%	0.89%	17.04%	53.20%	1.59%	54.79%
Cornellá de Llobregat	A1	56.26%	39.81%	3.93%	[illegible]	[illegible]	[illegible]	[illegible]	13.32%	5.19%	0.93%	19.44%	50.24%	1.50%	51.74%
Sant Boi de Llobregat	A1	65.09%	31.43%	3.48%	[illegible]	[illegible]	[illegible]	[illegible]	6.61%	4.46%	0.86%	11.93%	48.05%	1.44%	49.49%
El Prat de Llobregat	A1	66.78%	29.60%	3.55%	[illegible]	[illegible]	[illegible]	[illegible]	6.49%	4.07%	1.51%	12.07%	55.42%	1.66%	57.07%
L'Hospitalet de Llobregat	A1	55.98%	39.69%	4.33%	[illegible]	[illegible]	[illegible]	[illegible]	17.98%	4.94%	1.41%	24.33%	49.65%	1.49%	51.14%
Sant Feliu de Llobregat	A1	57.74%	38.00%	4.25%	[illegible]	[illegible]	[illegible]	[illegible]	7.10%	2.54%	1.04%	10.67%	47.05%	1.41%	48.46%
First Ring (average)	average	59.74%	36.23%	4.04%	[illegible]	[illegible]	[illegible]	[illegible]	10.38%	4.56%	1.10%	16.03%	50.21%	1.50%	51.71%
Viladecans	A2	56.93%	38.89%	4.18%	[illegible]	[illegible]	[illegible]	[illegible]	4.37%	3.92%	0.26%	8.54%	50.61%	1.51%	52.13%
Castelldefels	A2	59.38%	34.93%	5.69%	[illegible]	[illegible]	[illegible]	[illegible]	7.00%	3.41%	0.77%	11.18%	38.29%	1.14%	39.44%
Sant Cugat del Vallés	A2	56.70%	36.46%	6.84%	[illegible]	[illegible]	[illegible]	[illegible]	11.64%	1.20%	1.75%	14.59%	31.22%	0.93%	32.16%
Rubí	A2	59.94%	36.23%	3.84%	[illegible]	[illegible]	[illegible]	[illegible]	6.88%	1.62%	1.83%	10.33%	34.62%	1.03%	35.65%
Cerdanyola del Vallés	A2	60.14%	34.72%	5.14%	[illegible]	[illegible]	[illegible]	[illegible]	5.81%	2.20%	1.98%	9.98%	44.15%	1.32%	45.47%
Mollet del Vallés	A2	64.69%	32.53%	2.77%	[illegible]	[illegible]	[illegible]	[illegible]	3.82%	1.25%	0.80%	5.88%	50.74%	1.52%	52.26%
Second Ring (average)	average	59.63%	35.63%	4.74%	[illegible]	[illegible]	[illegible]	[illegible]	6.59%	2.27%	1.23%	10.08%	41.61%	1.24%	42.85%
Sabadell	SAT	73.04%	23.77%	3.19%	[illegible]	[illegible]	[illegible]	[illegible]	3.80%	6.18%	0.57%	10.55%	44.96%	1.34%	46.30%
Terrassa	SAT	76.48%	21.47%	2.05%	[illegible]	[illegible]	[illegible]	[illegible]	2.90%	4.47%	0.78%	8.15%	42.03%	1.26%	43.29%
Mataró	SAT	77.77%	19.75%	2.48%	[illegible]	[illegible]	[illegible]	[illegible]	3.10%	4.05%	0.78%	7.93%	51.81%	1.55%	53.36%
Vilanova I la Geltrú	SAT	77.12%	20.43%	2.44%	[illegible]	[illegible]	[illegible]	[illegible]	5.56%	1.46%	0.59%	7.62%	52.13%	1.56%	53.69%
Granollers	SAT	64.24%	32.88%	2.87%	[illegible]	[illegible]	[illegible]	[illegible]	4.39%	1.09%	0.99%	6.48%	48.64%	1.45%	50.09%
Vilafranca del Penedès	SAT	67.05%	29.43%	3.51%	[illegible]	[illegible]	[illegible]	[illegible]	3.17%	1.02%	0.92%	5.11%	53.21%	1.59%	54.80%
Satellite (average)	average	72.62%	24.62%	2.77%	[illegible]	[illegible]	[illegible]	[illegible]	3.82%	3.05%	0.77%	7.64%	48.80%	1.46%	50.26%

Table.App-16 Summary travel statistics for London and its region

	Area	Factor for averages	Transport Mode***								Council Area Population**		Density	Distance from	GDP*	Active population*		Number of jobs**		
			[illegible]	Trains	Bus	Other	Public	Walk	Bike	Non motorised	km²	2010	2005		GBP/person	>16 population	%	absolute	[illegible]	[illegible]
City of London	London	0.015	[illegible]	30%	4%	2%	44%	42%	0%	42%	2.9	8,700	3,348	0	32,069	7,401	76.30%	281,612	37,108	38.05
Camden	London	0.325	[illegible]	17%	17%	3%	37%	41%	3%	44%	21.7	215,200	9,925	3.3	32,069	154,785	72.60%	273,960	12,625	1.77
Islington	London	0.323	[illegible]	14%	30%	3%	45%	37%	3%	40%	14.8	211,900	14,318	5.8	32,069	157,860	74.69%	224,160	15,147	1.42
Westminster	London	0.337	[illegible]	15%	14%	3%	32%	47%	3%	50%	21.4	221,100	10,332	4.5	32,069	159,192	72.00%	555,255	24,920	3.35
Central London avg		1	[illegible]	15%	19%	2%	37%	42%	3%	45%	61	666,000	10,788	4	32,069	556,886		1,313,648	18,834	2.726
Hackney	A1	0.093	[illegible]	8%	28%	3%	37%	36%	8%	44%	19.0	234,200	12,295	7.6	17,884	183,472	60.80%	100,526	5,750	0.67
Hammersmith and Fulham	A1	0.073	[illegible]	16%	16%	3%	35%	38%	5%	43%	16.4	183,200	11,173	10.5	32,069	133,919	73.10%	145,294	8,739	1.07
Haringey	A1	0.095	[illegible]	15%	20%	1%	36%	32%	1%	33%	29.6	230,200	8,081	16.7	32,069	170,071	71.10%	79,603	2,701	0.47
Kensington and Chelsea	A1	0.058	[illegible]	13%	13%	3%	29%	41%	3%	44%	12.1	172,200	14,205	8	32,069	120,540	70.00%	131,389	10,837	1.09
Lambeth	A1	0.12	[illegible]	14%	22%	2%	38%	28%	2%	30%	26.8	303,500	11,328	4.1	32,069	221,859	73.10%	157,520	5,875	0.71
Lewisham	A1	0.106	[illegible]	13%	17%	1%	31%	27%	1%	28%	35.1	274,900	7,821	15.1	17,884	195,179	71.00%	78,022	2,221	0.4
Newham	A1	0.107	[illegible]	15%	16%	2%	33%	34%	1%	35%	36.2	268,600	7,426	13.7	17,884	185,472	60.00%	32,736	2,582	0.5
Southwark	A1	0.115	[illegible]	17%	28%	1%	41%	30%	1%	32%	28.9	288,800	10,006	3	32,069	206,781	71.60%	231,594	8,014	1.12
Tower Hamlets	A1	0.101	[illegible]	19%	16%	1%	36%	42%	2%	44%	19.8	254,200	12,851	6	17,884	184,200	72.50%	232,212	11,739	1.26
Wandsworth	A1	0.12	[illegible]	19%	13%	2%	34%	32%	3%	35%	34.5	303,200	8,849	11.1	17,884	222,549	73.40%	129,028	3,787	0.58
First Ring (average)	average	1	[illegible]	14%	19%	2%	35%	36%	3%	39%	256	2,622,200	8,767	8	24,877					
Barking and Dagenham	A2	0.038	[illegible]	9%	12%	1%	22%	32%	1%	33%	36.1	179,400	4,968	18.9	15,854	115,275	64.20%	48,373	1,340	0.42
Barnet	A2	0.071	[illegible]	7%	10%	2%	19%	30%	1%	31%	86.7	334,200	3,855	23.9	15,854	219,235	65.60%	138,119	1,592	0.63
Bexley	A2	0.047	[illegible]	6%	9%	1%	16%	23%	1%	24%	60.6	220,200	3,633	28.5	15,854	142,249	64.60%	71,125	1,174	0.50
Brent	A2	0.06	[illegible]	12%	15%	1%	28%	32%	1%	33%	43.2	283,000	6,544	15.8	18,539	184,516	65.20%	118,090	2,731	0.64
Bromley	A2	0.065	[illegible]	8%	8%	0%	16%	26%	0%	26%	150.1	306,400	2,041	17.8	18,079	198,547	64.80%	110,128	733	0.60
Croydon	A2	0.073	[illegible]	7%	14%	1%	22%	23%	1%	24%	85.5	347,000	4,011	19.4	18,079	228,675	65.90%	154,917	1,560	0.58
Ealing	A2	0.068	[illegible]	11%	13%	1%	25%	24%	2%	26%	55.5	320,000	5,797	18.1	18,639	213,808	66.40%	124,000	2,233	0.58
Enfield	A2	0.055	[illegible]	8%	14%	1%	23%	26%	1%	27%	80.8	296,300	3,666	11	15,854	193,186	65.20%	106,185	1,328	0.56
Greenwich	A2	0.051	[illegible]	12%	19%	1%	32%	24%	1%	25%	47.3	241,400	5,100	14.7	15,854	158,117	65.50%	83,802	1,770	0.53
Harrow	A2	0.047	[illegible]	8%	8%	0%	16%	33%	1%	34%	50.5	223,900	4,437	25.4	18,539	147,525	65.90%	79,239	1,489	0.53
Havering	A2	0.05	[illegible]	7%	9%	2%	18%	19%	1%	20%	112.4	234,600	2,087	25.6	15,854	153,608	65.50%	82,640	738	0.54
Hillingdon	A2	0.056	[illegible]	8%	10%	1%	19%	24%	1%	25%	115.7	265,900	2,298	29.5	18,539	175,494	66.00%	199,508	1,714	1.11
Hounslow	A2	0.051	[illegible]	8%	12%	1%	21%	28%	2%	30%	56.0	230,700	4,182	22.3	18,639	159,880	66.70%	134,200	2,399	0.84
Kingston upon Thames	A2	0.035	[illegible]	7%	8%	1%	16%	33%	2%	35%	37.3	157,100	4,218	20.6	18,079	106,671	67.90%	75,802	2,061	0.72
Merton	A2	0.043	[illegible]	12%	12%	1%	25%	34%	1%	35%	37.6	200,700	5,334	14.7	18,079	132,868	66.20%	79,075	1,842	0.55
Redbridge	A2	0.055	[illegible]	10%	9%	1%	20%	25%	1%	26%	56.4	261,200	4,630	19.9	18,539	171,085	65.50%	79,989	1,385	0.45
Richmond upon Thames	A2	0.04	[illegible]	11%	9%	2%	22%	33%	4%	37%	57.4	188,500	3,284	16.8	18,079	125,164	66.40%	82,606	1,438	0.66
Sutton	A2	0.04	[illegible]	7%	8%	1%	16%	23%	1%	24%	43.8	188,000	4,288	20.7	18,079	124,456	66.20%	73,940	1,618	0.57
Waltham Forest	A2	0.049	[illegible]	12%	11%	2%	25%	29%	1%	30%	38.8	232,700	5,996	14.6	15,854	150,700	64.80%	68,068	1,787	0.45
Second Ring (average)	average	1	[illegible]	11%	14%	1%	26%	30%	2%	32%	1,252.9	4,722,100	3,768	30	17,658					
Cambridge	SAT		[illegible]		12.00%	11.00%	23.00%	5.00%		5.00%	41.0	125,700	3,066	102	16,858	94,600	75.26%	102,160	2,492	1.08
Milton Keynes	SAT		[illegible]		14.00%	12.00%	26.00%	4.00%		4.00%	305.0	245,100	782	87	15,937	161,500	66.07%	151,010	401	0.94
Northampton	SAT		[illegible]		16.00%	11.00%	41.00%	4.00%		4.00%	80.1	212,100	2,648	108	15,478	141,600	66.75%	135,936	1,607	0.86
Oxford	SAT		[illegible]		14.00%	12.00%	26.00%	4.00%		4.00%	46.0	153,300	3,428	95	17,883	112,400	71.66%	121,332	2,638	1.08
Reading	SAT		[illegible]		14.00%	12.00%	26.00%	4.00%		4.00%	40.0	154,100	3,853	67	15,582	108,500	70.36%	101,000	2,550	0.94
Southend	SAT		[illegible]		12.00%	11.00%	23.00%	5.00%		5.00%	42.0	165,300	3,936	68	15,802	103,100	62.51%	74,520	1,774	0.72

APPENDIX II:
RESUMEN EN CASTELLANO
RESUMO EN GALEGO

Appendix II: Resumen en castellano

El crecimiento urbano experimentado durante las cuatro últimas generaciones no tiene parangón en la historia de la humanidad. El área urbanizada en los últimos sesenta años supera, con creces, el de las ciudades creadas en los cinco mil años anteriores. Se estima que hace aproximadamente una década se invirtió la histórica mayoría de población rural sobre la urbana en el planeta. El hito generador de este período de continua expansión se debió inicialmente a los avances tecnológicos que posibilitaron las sucesivas etapas de industrialización, en los cuales las actividades económicas se concentraron en torno a las nuevas fuentes de energía, nodos comerciales y centros de producción. La sociedad urbana industrial, aunque dura, era percibida como una alternativa a las penurias de la vida en el rural. Eran centros para el desarrollo de la cultura, el arte, la educación, la labor científica y la producción económica. Los logros científicos permitieron a la erradicación de enfermedades mortales, la predicción y la prevención de desastres naturales o la mejora de las condiciones laborales y popularización del ocio fueron posibles gracias a la concentración y la interacción de personas en entornos urbanos. Todavía hoy, las ciudades siguen siendo polos de atracción para las personas que buscan oportunidades y la prosperidad. De hecho, la progresiva mecanización del trabajo en los sectores primario y secundario ha impulsado un nuevo tipo de terciario basado, en gran medida, en la socialización y la creación de contactos. Actividades que son reforzadas, de nuevo, por los entornos urbanos.

Appendix II: Resumo en galego

O crecemento urbano experimentado durante as catro últimas xeracións non ten parangón na historia da humanidade. A área urbanizada nos últimos sesenta anos supera, amplamente, o das cidades creadas nos cinco mil anos anteriores. Estímase que fai aproximadamente unha década inverteuse a histórica maioría de poboación rural sobre a urbana no planeta. O fito xerador deste período de continua expansión debeuse, inicialmente, aos avances tecnolóxicos que posibilitaron as sucesivas etapas de industrialización, nos cales as actividades económicas concentráronse en torno ás novas fontes de enerxía, os nodos comerciais e os centros de produción. A sociedade urbana industrial, aínda que dura, era percibida como unha alternativa ás penurias da vida no rural. Eran centros para o desenvolvemento da cultura, a arte, a educación, o labor científico e a produción económica. Os logros científicos permitiron á erradicación de enfermidades mortais, a predición e prevención de desastres naturais ou a mellora das condicións laborais e a popularización do lecer foron posibles grazas á concentración e a interacción de persoas nas contornas urbanas. Aínda hoxe, as cidades seguen sendo polos de atracción para as persoas que buscan oportunidades e prosperidade. De feito, a progresiva mecanización do traballo nos sectores primario e secundario impulsou un novo tipo de terciario baseado, en gran medida, na socialización e a creación de contactos. Actividades que son reforzadas, de novo, nas cidades.

Pero las ciudades también concentran algunos de los aspectos más negativos de la actividad humana. Barrios marginales, de chabolas y barracas, rodean las megápolis del planeta. Contaminación, reducción de biodiversidad, crimen, y ciertas enfermedades (cáncer de pulmón, estrés...) se ven agravados por los efectos de la urbanización. Además, los habitantes de las ciudades son mucho más dependientes de recursos externos para subsistir, ya que carecen de la capacidad de los habitantes rurales para cultivar su propio alimento u obtener materias primas para su consumo directo. Las necesidades de la población urbana requieren de una compleja logística para organizar la extracción, transporte y distribución de agua, energía, alimentos y otros bienes, desde su origen hasta los puntos de consumo. Una vez consumidos, estos productos generan residuos que deben ser, a su vez, recogidos y eliminados en vertederos o plantas de tratamiento. Una gran parte de estos procesos afectan áreas que son externas a las ciudades, a distancias cada vez más largas, produciendo una degradación ambiental proporcional al tamaño y riqueza de la población que atendida. Dado que las ciudades han basado gran parte de su desarrollo en el intercambio comercial, su riqueza aumenta cuanto mayor sean los flujos de materiales, energía o alimentos que confluyen en ellas. Un instinto caníbal inherente a la economía urbana induce este círculo vicioso que menoscaba los intentos por reducir la voracidad consumista de las ciudades. Este sistema no era especialmente preocupante cuando las ciudades eran una excepción en una sociedad predominantemente rural o, incluso, cuando el exceso de consumo de las economías más avanzadas era parcialmente compensado con las estrecheces del llamado tercer mundo. Sin embargo, el reciente despertar de los países ubicados en alguna de las zonas más densamente pobladas del mundo, como el Sureste Asiático o Brasil, ha conducido a un rápido proceso de urbanización en esas zonas, transformando sociedades austeras y rurales en nuevos consumidores urbanitas. Se ha estimado que las ciudades ya consumen aproximadamente el 60-80% de la energía mundial y son responsables del 80 % de las emisiones de CO2[1]. Con la adhesión de los países emergentes a la economía de consumo, todas las evidencias indican que la presión sobre los recursos naturales y energéticos tenderá a aumentar durante los próximos años. Por otra parte, el 80 % de la energía proviene de fuentes fósiles[2], cuyo agotamiento se estima que ocurrirá durante la próxima generación[3]. En este escenario, la planificación de las ciudades para un contexto sin energías fósiles es un deber ineludible que no permite más demora, ya que las estructuras que construimos hoy serán heredadas por las generaciones futuras.

1 Burdett & Rhode, 2012 Marr & Wehner, 2012
2 Nakicenovic, 2010
3 Estimación para el agotamiento de las reservas de petróleo: 25 años Gas Natural: 40 años Carbón: 200 años (Edwards, 2010)

Pero as cidades tamén concentran algúns dos aspectos máis negativos da actividade humana. Barrios marxinais, de chabolas e barracas, rodean as megápolis do planeta. Contaminación, redución da biodiversidade, crime, e certas enfermidades (cancro de pulmón, estres...) vense agravados polos efectos da urbanización. Ademais, os habitantes das cidades son moito máis dependentes dos recursos externos para subsistir, xa que carecen da capacidade dos habitantes rurais para cultivar o seu propio alimento ou obter materias primas para o seu consumo directo. As necesidades da poboación urbana requiren dunha complexa loxística para organizar a extracción, transporte e distribución de auga, enerxía, alimentos e outros bens, dende a súa orixe ata os puntos de consumo. Unha vez consumidos, estes produtos xeran residuos que deben ser, á súa vez, recollidos e eliminados nos vertedoiros ou plantas de tratamento. Unha gran parte destes procesos afectan áreas que son externa ás cidades, a distancias cada vez máis longas, producindo unha degradación ambiental proporcional ao tamaño e riqueza da poboación que é atendida. Dado que as cidades basearon gran parte do seu desenvolvemento no intercambio comercial, a súa riqueza aumenta canto maior sexan os fluxos de materiais, enerxía ou alimentos que conflúen nelas . Un instinto caníbal inherente á economía urbana induce este círculo vicioso que menoscaba os intentos por reducir a voracidade consumista das cidades. Este sistema non era especialmente preocupante cando as cidades eran unha excepción nunha sociedade predominantemente rural ou, cando o exceso de consumo das economías máis avanzadas era parcialmente compensado coas estreiteces do chamado terceiro mundo. Con todo, o recente espertar dos países situados nalgunha das zonas más densamente poboadas do mundo, como o Sueste Asiático ou Brasil, conduciu a un rápido proceso de urbanización nesas zonas, transformando sociedades austeras e rurais en novos consumidores urbanos. Estimouse que as cidades xa consumen aproximadamente o 60-80% da enerxía mundial e son responsables do 80 % das emisións de CO2[1]. Coa adhesión dos países emerxentes á economía de consumo, todas as evidencias indican que a presión sobre os recursos naturais e enerxéticos tenderá a aumentar durante os próximos anos. Por outra banda, o 80 % da enerxía provén de fontes fósiles[2], cuxo esgotamento estímase que ocorrerá durante a próxima xeración[3]. Neste escenario, a planificación das cidades para un contexto sen enerxías fósiles é un deber ineludible que non permite máis demora, xa que as estruturas que construímos hoxe serán herdadas polas xeracións futuras.

El problema energético desde la perspectiva de la generación

Desde hace décadas se han venido desarrollando tecnologías basadas en fuentes renovables para reemplazar las energías convencionales. Viento y la energía solar se presentan como las alternativas más prometedoras, dada su amplia disponibilidad en distintas zonas del planeta y el hecho de que su rendimiento anual ha aumentado un promedio del 30 % en los últimos años[4]. Según el Premio Nobel Walter Kohn, si se sostuviera este ritmo de crecimiento, los niveles actuales de demanda de energía podrían ser satisfechas por sistemas eólicos y energía solar en dos o tres décadas. Obviamente, esta es una hipótesis muy optimista que se contradice con el escenario actual de recortes en investigación. La energía hidráulica es un recurso renovable largamente asentado que suministra alrededor del 6 % de la energía y cerca del 15% de la electricidad mundial[5]. El principal problema para extender su uso radica en la oposición a nuevas presas por parte de comunidades locales y grupos ecologistas. Por otra parte, es muy dependiente de las condiciones climáticas y tanto las inundaciones como las sequías pueden afectar su funcionamiento. Entre las alternativas que se han explorado en las últimas décadas se incluyen la geotérmica, mareas, olas, biomasa, cogeneración y la implantación de redes inteligentes para maximizar la eficiencia, así como sistemas de captura de carbono para mitigar el impacto de las emisiones de gas de efecto invernadero. Todas estas tecnologías tienen dos cosas en común: se caracterizan por una densidad de potencia espacial relativamente baja y se centran en el lado de la provisión de energía. Los equipos de planificación tendrán que analizar los sistemas que son adecuados para cada caso, y donde deben situarse para mitigar su impacto ambiental.

El problema energético desde la perspectiva de la demanda

Las dificultades de implementación de las energías renovables y su posible insuficiencia para satisfacer un consumo creciente requieren una consideración más profunda desde el punto de vista de la demanda. La percepción de una disponibilidad energética ilimitada ha generado unas expectativas y cierta complacencia que impiden mejoras en la eficiencia a través de los usuarios finales. El consumo mundial de energía aumenta de forma continua a pesar de las evidencias que claman por la necesidad de adaptación a un nuevo escenario. Muchos de los edificios y ciudades que se están diseñando actualmente no podrán ser utilizados sin un aporte de energía enorme, que pronto será inasumible.

El enfoque de la eficiencia energética desde la perspectiva de la demanda implica tres niveles de acción:

a**) El análisis de los patrones de la demanda**. La comprensión de los factores que generan la demanda es el primer paso para identificar prioridades y evaluar potenciales

4 Kohn, 2010
5 Roaf, Crichton & Nicol, 2009

O problema enerxético desde a perspectiva da xeración

Desde fai décadas viñéronse desenvolvendo tecnoloxías baseadas en fontes renovables para substituír ás enerxías convencionais. As enerxías eólica e solar preséntanse como as alternativas máis prometedoras, dada a súa ampla dispoñibilidade en distintas zonas do planeta e o feito de que o seu rendemento anual aumentou unha media do 30 % nos últimos anos[4]. Segundo o Premio Nobel Walter Kohn, si se sostivese este ritmo de crecemento, os niveis actuais de demanda de enerxía poderían ser satisfeitas por sistemas eólicos e enerxía solar en dous ou tres décadas. Obviamente, esta é unha hipótese moi optimista que se contradí co escenario actual de recortes en investigación . A enerxía hidráulica é un recurso renovable largamente asentado que fornece ao redor do 6 % da enerxía e cerca do 15% da electricidade mundial[5]. O principal problema para estender o seu uso radica na oposición a novas presas por parte de comunidades locais e grupos ecoloxistas. Por outra banda, é moi dependente das condicións climáticas, e tanto as inundacións como as secas poden afectar o seu funcionamento. Entre as alternativas que se exploraron nas últimas décadas inclúense a xeotérmica, mareas, olas, biomasa, coxeneración e a implantación de redes intelixentes para maximizar a eficiencia, así como sistemas de captura de carbono para mitigar o impacto das emisións de gas de efecto invernadoiro. Todas estas tecnoloxías teñen dúas cousas en común: caracterízanse por unha densidade de potencia espacial relativamente baixa e céntranse no lado da provisión de enerxía. O primeiro aspecto afecta de forma directa ao planeamento urbanístico, xa que se deben designar grandes extensións de solo para este fin. Os equipos de planificación terán que analizar os sistemas máis adecuados para cada caso, e onde deben situarse para minimizar o seu impacto ambiental.

O problema enerxético desde a perspectiva da demanda

As dificultades da posta en marcha das enerxías renovables e a súa posible insuficiencia para satisfacer un consumo crecente, requiren unha consideración máis profunda desde o punto de vista da demanda. A percepción dunha dispoñibilidade enerxética ilimitada xerou unhas expectativas e certa compracencia que impiden melloras na eficiencia a través dos usuarios finais. O consumo mundial de enerxía aumenta de forma continua malia as evidencias que claman pola necesidade de adaptación a un novo escenario. Moitos dos edificios e cidades que se están deseñando actualmente non poderán ser utilizados sen un aporte de enerxía enorme, que pronto será inasumible.

O enfoque da eficiencia enerxética de dende a perspectiva da demanda implica tres niveles de acción:

a)**A análise dos patróns da demanda**. A comprensión dos factores que xeran a demanda é o primeiro paso para estrategias. En términos generales tres sectores: la operación de edificios, el transporte y las actividades industriales (incluyendo la generación de energía) concentran la mayor parte de las necesidades energéticas, representando aproximadamente un tercio de la demanda cada uno. El análisis pormenorizado revela cómo los edificios residenciales son el principal sector de consumo en la mayoría de países europeos. Representa más del 40 % de la demanda total de energía en el Reino Unido, Alemania o Francia, y casi el 30 % en los países mediterráneos, como España, Italia o Grecia. La energía doméstica se destina, principalmente, a calefacción e iluminación. En el Reino Unido, por ejemplo, la calefacción doméstica representa el 20 % del consumo energético nacional.

b) Diseño y prescripción de estrategias para modificar los patrones de demanda. Algunos estudios sostienen que alrededor del 70 % de la energía consumida está influida, directa o indirectamente por el planeamiento urbanístico[6]. Es un hecho constatable que el diseño de ciudades y edificios tiene un fuerte impacto en su futura dependencia de combustibles convencionales. Algunas estrategias pasivas de diseño se han implementado con cierto éxito a escala del edificio. Los sistemas de calefacción solar, el incremento de los niveles de aislamiento y el control de la ventilación han contribuido a mejorar notablemente la eficiencia energética de los edificios en las últimas décadas. Incluso se han desarrollado prototipos que demuestran la viabilidad de edificios neutros, es decir, que proporcionan espacios confortables sin generar CO_2, a través de la combinación de estrategias de diseño pasivo y la utilización de tecnologías energéticas alternativas. Sin embargo, a escala urbana apenas existen experiencias similares, ya la mayor parte del conocimiento se basa en teorías que difícilmente pueden ser verificadas a través de prototipos o experimentos reales.

Actualmente existe un amplio consenso sobre la idea de que la eficiencia energética de las ciudades se puede mejorar a través de la densidad, la compacidad y la mezcla de usos. Estas afirmaciones se basan en dos supuestos fundamentales: en primer lugar, la reducción de la movilidad obligada, ya que la distancia entre actividades se reduce y, en segundo lugar, la mayor conservación de energía en los edificios en las ciudades que se desarrollan verticalmente en vez de horizontalmente.

c) Aplicación de políticas y estrategias. La elaboración de agendas para implementar las medidas de eficiencia energética han sido generalmente asumidas por los gobiernos y las administraciones públicas. En Europa, los acuerdos internacionales, las directivas y los documentos-guía crean un marco común que debe ser trasladado y adaptado a los estados miembros. La EPBD[7] y sus revisiones han

6 Owens ,1992 and Williams et al, 2000

7 Energy Performance of Buildings Directive 2010/31/EU

identificar prioridades e avaliar as posibles estratexias. En termos xerais, tres sectores: a operación de edificios, o transporte e as actividades industriais (incluíndo a xeración de enerxía) concentran a maior parte das necesidades enerxéticas, representando aproximadamente un terzo da demanda cada un deles. A análise pormenorizada revela como os edificios residenciais son o principal sector de consumo na maioría de países europeos. Representa máis do 40 % da demanda total de enerxía no Reino Unido, Alemaña ou Francia, e case o 30 % nos países mediterráneos, coma España, Italia ou Grecia. A enerxía doméstica destínase, principalmente, a calefacción e iluminación. No Reino Unido, por exemplo, a calefacción doméstica representa o 20 % do consumo enerxético nacional.

b) Deseño e prescrición de estratexias para modificar os patróns de demanda. Algúns estudos sosteñen que ao redor do 70 % da enerxía consumida está influída, directa ou indirectamente pola planeamento urbanístico[6]. É un feito verificable que o deseño de cidades e edificios ten un forte impacto na súa futura dependencia de combustibles convencionais. Algunhas estratexias pasivas de deseño desenvolvéronse con certo éxito a escala do edificio. Os sistemas de calefacción solar, o incremento dos niveis de illamento e o control da ventilación contribuíron a mellorar notablemente a eficiencia enerxética dos edificios nas últimas décadas. Tamén se desenvolveron prototipos que demostran a viabilidade de edificios neutros, é dicir, que proporcionan espazos confortables sen xerar CO_2, a través da combinación de estratexias de deseño pasivo e a utilización de tecnoloxías enerxéticas alternativas. Con todo, a escala urbana apenas existen experiencias similares, xa que a maior parte do coñecemento baséase en teorías que dificilmente poden ser verificadas a través de prototipos ou experimentos reais.

Actualmente existe un amplo consenso sobre a idea de que a eficiencia enerxética das cidades pódese mellorar a través da densidade, a compactidade e a mestura de usos. Estas afirmacións baséanse en dous supostos fundamentais: en primeiro lugar, a redución da mobilidade obrigada, xa que a distancia entre actividades redúcese e, en segundo lugar, a maior conservación de enerxía nos edificios nas cidades que se desenvolven verticalmente con respecto das que o fan horizontalmente.

c) Aplicación de políticas e estratexias. A elaboración de axendas para por en práctica medidas de eficiencia enerxética foron xeralmente asumidas polos gobernos e as administracións públicas. En Europa, os acordos internacionais, as directivas e os documentos-guía crean un marco común que debe ser trasladado e adaptado aos estados membros. A EPBD[7] e as súas revisións estableceron ambiciosos obxectivos para aumentar a eficiencia dos edificios. Requirirase que as novas establecido ambiciosos objetivos para aumentar la eficiencia de los edificios. Se requerirá que las nuevas construcciones a partir del año 2020 tengan un comportamiento " de energía casi nula"[8]. En cuanto a las ciudades, existen numerosos documentos de asesoramiento y guía, pero ninguno de obligada aplicación. El Libro Verde Sobre el Medio Ambiente Urbano[9] propone objetivos para la "mejora el medio ambiente urbano ", que incluye políticas para reducir " el impacto de las ciudades " por medio de una " gestión de la energía urbana" más eficiente. Se enumeran una serie de áreas de actuación a ser desarrolladas por los Estados miembros para su incorporación a las normativas nacionales de planeamiento urbanístico y territorial. El transporte urbano y la eficiencia energética de los edificios son dos de estas áreas concretas. El texto define unos principios generales, como el fomento del transporte público o la conservación de la energía en los edificios. Aunque algunos estados (por ejemplo España) han desarrollado directrices detalladas sobre la base de esos principios, ni son de obligado cumplimiento ni han sido aplicadas por los organismos de competentes.

Aunque el conocimiento sobre los patrones de comportamiento de la energía consumida en las ciudades está muy desarrollado, los mayores esfuerzos se han enfocado hasta ahora en el lado de la eficiencia en la generación y el suministro. Se ha concebido tecnologías alternativas y sofisticados sistemas con el fin de mejorar la eficiencia en la producción de energía y encontrar soluciones frente al previsible agotamiento de las fuentes convencionales. El coche eléctrico, las redes inteligentes y las energías renovables han sido ampliamente investigados y su uso podría generalizarse en un plazo relativamente corto. Además, los instrumentos de análisis y tratamiento de datos más recientes han abierto nuevas oportunidades para la compresión de los procesos urbanos, también los relativos a la demanda de energía. Sin embargo, la transformación de esta gran cantidad de información en instrumentos de planificación útiles y viables no ha progresado a la misma velocidad. El exceso de confianza en el aislamiento térmico de edificios como medida de ahorro ha desincentivado la investigación otras áreas del diseño, mientras que la densidad y la mezcla de usos son vistas como la panacea para reducir la necesidad de viajar y el gasto energético en transporte. Como consecuencia, se realizan prescripciones deterministas para su aplicación estandarizada, sin tener en cuenta la especificidad de cada caso. Los códigos de construcción determinan umbrales mínimos de aislamiento para cada zona climática, lo que lleva a la indiferencia de otros factores, tales como la interacción del usuario, la forma del edificio y, sobre todo, el contexto urbano en que se sitúa el edificio.

construcións, a partir do ano 2020, teñan un comportamento " de enerxía case nula"[8]. En canto ás cidades, existen numerosos documentos de asesoramento e guía, pero ningún de obrigada aplicación. O Libro Verde Sobre o Medio Ambiente Urbano[9] propón obxectivos para a mellora do medio ambiente urbano ", que inclúe políticas para reducir " o impacto das cidades " por medio dunha " xestión da enerxía urbana" máis eficiente. Enuméranse unha serie de áreas de actuación a ser desenvolvidas polos estados membros para a súa incorporación nas normativas nacionais de planeamento urbanístico e territorial. O transporte urbano e a eficiencia enerxética dos edificios son dous destas áreas concretas. O texto define uns principios xerais, como o fomento do transporte público ou a conservación da enerxía nos edificios. Aínda que algúns estados (por exemplo España) desenvolveron directrices detalladas sobre a base deses principios, nin son de obrigado cumprimento nin foron aplicadas polos organismos competentes. Retrospectivamente, pódese dicir que hai unha sobreprodución de documentos tecnocráticos sobre a xestión enerxética no urbanismo que non se traduciu en resultados positivos na práctica do planeamento.

Aínda que o coñecemento dos patróns de comportamento da enerxía consumida nas cidades está moi desenvolvido, os maiores esforzos enfocáronse ata agora no lado da eficiencia na xeración e a distribución. Concibíronse tecnoloxías alternativas e sofisticados sistemas co fin de mellorar a eficiencia na produción de enerxía e atopar solucions fronte ao previsible esgotamento das fontes convencionais. O coche eléctrico, as redes intelixentes e as enerxías renovables foron amplamente investigados, e o seu uso podería xeneralizarse nun prazo relativamente curto. Ademais, os instrumentos máis recentes de análise e tratamento de datos abriron novas oportunidades para a compresión dos procesos urbanos, tamén os relativos á demanda de enerxía. Con todo, a transformación desta gran cantidade de información en instrumentos de planificación útiles e viables non progresou á mesma velocidade. O exceso de confianza no illamento térmico de edificios como medida de aforro desincentivou a investigación doutras áreas do deseño, mentres que a densidade e a mestura de usos son vistas como a panacea para reducir a necesidade de viaxar e o gasto enerxético do transporte. Como consecuencia, fanse prescricións deterministas para a súa aplicación estandarizada, sen ter en conta a especificidade de cada caso. Os códigos de construción determinan limiares mínimos de illamento para cada zona climática, o que leva á indiferenza doutros factores, tales como a interacción do usuario, a forma do edificio e, sobre todo, o contexto urbano en que se sitúa o edificio. De un modo similar, a aposta pola densidade estendeuse de norte a sur e de oeste a leste. Tanto Londres como Barcelona aspiran a ela, malia partir

8 Directiva 2010/31/UE del Parlamento Europeo y del Consejo relativa a la eficiencia energética de los edificios
9 CEC, 1990

Objetivos de la investigación

El principal objetivo de esta investigación es explorar la influencia de la forma urbana en la demanda energética de las ciudades para, a través de ese conocimiento incidir sobre los procesos de planificación y desarrollo en aras de una mayor sostenibilidad del sistema urbano. Se asume la necesidad de crear nuevos instrumentos de planeamiento que hagan posible la efectiva implementación de estrategias definidas en el marco de la sostenibilidad y se revisarán críticamente las teorías que abogan por una mayor densidad, añadiendo evidencias y algunas connotaciones a sus argumentos. La hipótesis de la investigación desafía algunas de las convenciones establecidas y revisa los métodos estandarizados de planificación. A pesar de que la energía es un elemento principal en la investigación, sólo representa una vista parcial sobre un tema complejo, lo cual podría derivar en conclusiones deterministas. La selección de casos de estudio proporciona un marco amplio, a la vez que concreto y realista, en el que confluyen las fuerzas de cambio en la ciudad post-industrial. El punto de partida de la investigación se podría sintetizar en una pregunta inicial en la que se cuestionan las teorías más aceptadas sobre la sostenibilidad urbana:

"Es la ciudad compacta la forma urbana más sostenible para las ciudades actuales y futuras?"

Los tres temas principales implicados en esta cuestión estructurarán la investigación subsiguiente. Sin embargo, antes de obtener una respuesta a esta pregunta, se requiere una revisión sobre algunos conceptos fundamentas, lo cual da lugar a nuevos interrogantes :

• En cuanto a los Procesos y Forma Urbana:

- ¿Cómo se define una ciudad compacta?
- ¿Qué ventajas ofrece?
- ¿Qué otras definiciones morfológicas se pueden extraer de las ciudades contemporáneas?
- ¿Cómo pueden ser definidas?
- ¿Por qué son relevantes las clasificaciones de la forma urbana?
- ¿Existe alguna relación entre forma urbana y otros procesos?

• En cuanto al Metabolismo y el Desarrollo Sostenible Urbano:

- ¿Cómo se define una ciudad sostenible?
- ¿Cuáles son los indicadores de comportamiento que la caracterizan?
- ¿Cuáles son las principales ventajas de la compactación urbana en un marco sostenible?
- ¿Qué relación existe entre los patrones de energía y la forma urbana?

• En cuanto a las transformaciones morfológicas en las

dende polos opostos, como paradigmas de formas extensivas e intensivas de desenvolvemento urbano respectivamente.

Obxectivos da investigación

O principal obxectivo desta investigación é explorar a influencia da forma urbana na demanda enerxética das cidades para, a través dese coñecemento incidir sobre os procesos de planificación e desenvolvemento en aras dun comportamento máis sustentable do sistema urbano. Asúmese a necesidade de crear novos instrumentos de planeamento que fagan posible a efectiva aplicación de estratexias definidas no marco da desenvolvemento sustentable e revisaranse criticamente as teorías que avogan por unha maior densidade, engadindo evidencias e algunhas connotacións a os seus argumentos. A eficacia de cada estratexia pode ser moito maior si as intervencións son adaptadas ás características específicas de cada situación. A hipótese da investigación desafía algunhas das convencións establecidas e revisa os métodos estandarizados de planificación. Malia que a enerxía é un elemento principal na investigación, só representa unha vista parcial sobre un tema complexo, o cal podería derivar en conclusións deterministas. A selección de casos de estudo proporciona un marco amplo, á vez que concreto e realista, no que conflúen as forzas de cambio na cidade post-industrial. O punto de partida da investigación poderíase sintetizar nunha pregunta inicial na que se cuestionan as teorías máis aceptadas sobre o feito sustentable na cidade:

"É a cidade compacta a forma urbana máis sustentable para as cidades actuais e futuras?"

Os tres temas principais implicados nesta cuestión estruturarán a investigación subseguinte. Con todo, antes de obter unha resposta a esta pregunta, requírese unha revisión sobre algúns conceptos fundamentas, o cal da lugar a novos interrogantes :

• En canto aos Procesos e Forma Urbana :

- ¿Como se define unha cidade compacta?
- ¿Que vantaxes ofrece?
- ¿Que outras definicións morfolóxicas se poden extraer das cidades contemporáneas?
- ¿Como poden ser definidas?
- ¿Por que son relevantes as clasificacións da forma urbana?
- ¿Existe algunha relación entre forma urbana e outros procesos?

• En canto ao Metabolismo e o Desenvolvemento Urbano Sustentable:

- ¿Como se define unha cidade sustentable?
- ¿Cales son os indicadores de comportamento que a caracterizan?
- ¿Cales son as principais vantaxes da compactidade

ciudades post- industriales

- ¿Qué procesos de compactación o densificación conllevan?
- ¿Cuáles han sido las implicaciones sociales?
- ¿Qué instrumentos existen para diseñar, facilitar o controlar esos procesos urbanos?

Estructura de la tesis

El documento de tesis se ha organizado en tres niveles diferentes. En primer lugar, en un nivel más general, la tesis se divide en dos partes: la primera es más teórica y la segunda parte es más práctica. El segundo nivel de organización contiene cuatro secciones, dos en cada una de las partes y, por último, el nivel inferior se corresponde con los diez capítulos de los que consta el documento (sin contar la introducción y las conclusiones). Los capítulos no siguen una rígida estructura lineal, pero, al contrario, se pueden leer en secuencia alternativa sin menoscabo de la legibilidad de las líneas principales de argumentación. Cada capítulo incluye una descripción detallada de cada uno de los subtemas, con un estudio crítico de los precedentes, un desarrollo analítico y una breve conclusión, resumiendo los principales puntos analizados.

El texto se complementa con abundante material gráfico. Planos y esquemas son, a la vez, herramientas analíticas e ilustrativas, aunque su principal función es la de facilitar la comprensión de los argumentos propuestos. La tesis contiene más de 800 ilustraciones, aproximadamente el 70 % de las mismas han sido elaboradas por el autor como parte de su investigación.La estructura general de la tesis se describe en la siguiente tabla:

Parte 1: Antecedentes teóricos. En la primera parte se revisan los conceptos fundamentales, en particular, la forma urbana y la sostenibilidad. Se trata de una revisión crítica, en la que se analizan y cuestionan los precedentes teóricos. Aunque es principalmente teórica, esta parte incorpora una cantidad importante de trabajo analítico, que permite introducir hallazgos originales en cada capítulo. La morfología urbana es una constante en esta parte ya que en los diferentes aspectos tratados son analizados en base a su relación con este tema.

Sección 1: Contexto y Principios Fundamentales. En esta sección se parte de la definición de ciudad y forma urbana para establecer un marco general de la investigación. Los siguientes capítulos abarcan desde la evaluación de la idoneidad del concepto de sostenibilidad a temas más específicos, como la energía asociada a edificios y transporte. La revisión bibliográfica, recopilando diferentes puntos de vista, con sus argumentos y evidencias es una base importante de la investigación en esta sección.

urbana en un marco sustentable?

- ¿Que relación existe entre os patróns de enerxía e a forma urbana?

• En canto ás transformacións morfolóxicas nas cidades post- industriais

- ¿Que procesos de compactidade ou densificación desencadean?
- ¿Cales foron as implicacións sociais?
- ¿Que instrumentos existen para deseñar, facilitar ou controlar eses procesos urbanos?

Estrutura da tese

O documento de tese organizouse en tres niveis diferentes. En primeiro lugar, nun nivel máis xeral, a tese divídese en dous partes: a primeira é máis teórica e a segunda parte é máis práctica. O segundo nivel de organización contén catro seccións, dúas en cada unha das partes e, para rematar, o nivel inferior correspóndese cos dez capítulos dos que consta o documento (sen contar a introdución e as conclusións). Os capítulos non seguen unha ríxida estrutura lineal, senón que pódense ler en secuencia alternativa sen menoscabo do entendemento das liñas principais de argumentación. Cada capítulo inclúe unha descrición detallada de cada un dos subtemas, cun estudo crítico dos precedentes, un desenvolvemento analítico e unha breve conclusión, resumindo os principais puntos analizados.

O texto se complementa con abundante material gráfico. Planos e esquemas son, á vez, ferramentas analíticas e ilustrativas, aínda que a súa principal función é a de facilitar a comprensión dos argumentos propostos. A tese contén máis de 800 ilustracións, aproximadamente o 70 % das mesmas foron elaboradas polo autor como parte da súa investigación.

A estrutura xeral da tese descríbese na seguinte táboa:

Parte 1: Antecedentes teóricos. Na primeira parte revísanse os conceptos fundamentais, en particular, a forma urbana e o feito sustentable. Trátase dunha revisión crítica, na que se analizan e cuestionan os precedentes teóricos. Aínda que é principalmente teórica, esta parte incorpora unha cantidade importante de traballo analítico, que permite introducir achados orixinais en cada capítulo. A morfoloxía urbana é unha constante nesta parte xa que os diferentes aspectos tratados son analizados en base á súa relación con este tema.

Sección 1: Contexto e Principios Fundamentais. Nesta sección pártese da definición de cidade e forma urbana para establecer un marco xeral da investigación. Os seguintes capítulos abarcan desde a avaliación da idoneidade do concepto sustentable a temas máis específicos, coma a enerxía asociada aos edificios e o transporte. A revisión bibliográfica, recompilando diferentes puntos de vista, cos seus argumentos e evidencias é a base desta sección.

Capítulo 1: Introducción

Capítulo 2: El estudio de Morfología Urbana. Una de las principales objeciones que puede hacerse sobre la mayoría de estudios sobre forma urbana sostenible es su falta de relación con los postulados clásicos de morfología. En lugar crear nuevas definiciones a partir de la nada, este capítulo presenta una revisión de las referencias clásicas, que informa e inspira una clasificación sintética de la forma urbana. Los párrafos iniciales explican la relevancia de la tipificación de las ciudades según su estructura física. El estudio de la forma ha sido abordado con diferentes propósitos y desde diferentes ángulos y escalas: desde los geógrafos alemanes como Von Thünen y Christaller , que se centraban en la economía y los patrones de usos del suelo a la interpretación de las ciudades como puntos de confluencia de flujos inmateriales . Los últimos párrafos del capítulo tratan sobre las conexiones entre la forma y los patrones de comportamiento en distintos sectores y procesos. Esta parte se visualiza a través del estudio de veintiséis regiones europeas. El análisis espacial de estas regiones metropolitanas permite realizar nuevas definiciones de la ciudad compacta y mixta. Londres, Bruselas o Colonia se caracterizan por sus formas extensivas y monofuncionales de crecimiento urbano, como la antítesis de la ciudad compacta, concepto que responde mejor a la realidad de ciudades como Barcelona, Madrid o Lisboa. El estudio de la correspondencia entre estas nuevas definiciones de la forma urbana y una serie de indicadores clave preparan el terreno para una discusión más profunda sobre la evaluación cualitativa, que será el punto de partida del siguiente capítulo.

Capítulo 3: El paradigma de la Ciudad Sostenible como cuestión morfológica. Este capítulo tiene como objetivo la identificación de criterios inequívocos para definir el buen comportamiento de la ciudad, según la interpretación de los objetivos consensuados en el marco del desarrollo sostenible. Consiste en una reflexión puramente teórica sobre la evolución de los criterios para definir las metas del planeamiento, de acuerdo con cada contexto, desde la aparición del urbanismo moderno hasta el momento actual. Este estudio retrospectivo se inicia con la explosión urbana que se produjo después de la revolución industrial, cuyas consecuencias sobre la clase obrera dio lugar a una conciencia ambiental de inspiración filantrópica y antropocéntrica. La solución a los problemas de la ciudad industrial se tradujo en los primeros reglamentos de planeamiento urbano, que incorporaron medidas higienistas para mejorar la ventilación y el acceso solar. La posguerra de la Segunda Guerra Mundial trajo un nuevo orden de prioridades que surgió, en parte, debido a la necesidad de reconstrucción y, en parte, debido a las mejoras que se habían logrado gracias a las reformas anteriores. En este período, la atención se centró en el medio natural. La sociedad adquirió consciencia del impacto ecológico de las actividades humanas después de que una serie de accidentes industriales con graves consecuencias sobre el

Capítulo 1: Introducción

Capítulo 2: O estudo de Morfoloxía Urbana. Unha das principais críticas que se poden facer sobre a maioría de estudos que tratan a forma urbana sustentable é a súa falta de relación cos postulados clásicos de morfoloxía . En lugar crear novas definicións a partir da nada, este capítulo presenta unha revisión das referencias clásicas, que informa e inspira unha clasificación sintética da forma urbana. Os parágrafos iniciais explican a relevancia da tipificación das cidades segundo a súa estrutura física. O estudo da forma foi abordado con diferentes propósitos e desde diferentes ángulos e escalas: desde os xeógrafos alemáns como Von Thünen e Christaller , que se centraban na economía e os patróns de usos do solo á interpretación das cidades como puntos de confluencia de fluxos inmateriais . Os últimos parágrafos do capítulo tratan sobre as conexións entre a forma e os patróns de comportamento en distintos sectores e procesos. Esta parte visualízase a través do estudo de vinte e seis rexións europeas. A análise espacial destas rexións metropolitanas permite realizar novas definicións da cidade compacta e mixta. Londres, Bruxelas ou Colonia caracterizanse polas súas formas extensivas e monofuncionais de crecemento urbano, como a antítese da cidade compacta, concepto que responde mellor á realidade de cidades coma Barcelona, Madrid ou Lisboa. O estudo da correspondencia entre estas novas definicións da forma urbana e unha serie de indicadores clave preparan o terreo para unha discusión máis profunda sobre a avaliación cualitativa, que será o punto de partida do seguinte capítulo.

Capítulo 3: O paradigma da Cidade Sustentable como cuestión morfolóxica. Este capítulo ten como obxectivo a identificación de criterios inequívocos para definir o bo comportamento da cidade, segundo a interpretación dos obxectivos acordados no marco do desenvolvemento sustentable. Consiste nunha reflexión puramente teórica sobre a evolución dos criterios para definir as metas da planeamento, de acordo con cada contexto, desde a aparición do urbanismo moderno ata o momento actual. Este estudo retrospectivo iníciase coa explosión urbana que se produciu logo da revolución industrial, cuxas consecuencias sobre a clase obreira deu lugar a unha conciencia ambiental de inspiración filantrópica e antropocéntrica. A solución aos problemas da cidade industrial traduciuse nos primeiros regulamentos de planeamento urbano, que incorporaron medidas hixienistas para mellorar a ventilación e o acceso solar. A posguerra da Segunda Guerra Mundial trouxo unha nova orde de prioridades que xurdiu, en parte, debido á necesidade de reconstrución e, en parte, debido as melloras acadadas grazas ás reformas anteriores. Neste período, a atención centrouse no medio natural. A sociedade adquiriu consciencia do impacto ecolóxico das actividades humanas despois de que unha serie de accidentes industriais con graves consecuencias sobre o medio recibisen unha ampla cobertura nos medios.

medio hubieran recibido una amplia cobertura mediática. La presión social obligó a los gobiernos a actuar, proponiendo evaluaciones específicas sobre el impacto en el medio ambiente como parte obligatoria de los planes de desarrollo urbano y los proyectos industriales. Posteriormente, la crisis en las industrias occidentales, que comenzaron su declive a partir de los años sesenta , trajo el desempleo masivo al corazón de las ciudades e inspiró a una nueva agenda en el marco del estado del bienestar : el desarrollo sostenible. Las preocupaciones sociales y ambientales que se plantearon en los dos ciclos anteriores se complementan ahora con objetivos económicos, para completar el triángulo de la sostenibilidad.

Capítulo 4: Energía de los edificios y forma urbana. El concepto de satisfacción de las necesidades de las generaciones presentes y futuras implica una seria consideración de los recursos disponibles y el equilibrio entre el consumo y las tasas de reposición. La analogía ecológica, en la cual se comparan las ciudades con ecosistemas, se ha utilizado para crear un método sistemático de evaluación de los flujos que sustentan las actividades urbanas, incluyendo la energía, los alimentos y el agua. Estos flujos son los que deben mantenerse dentro de parámetros asumibles por el sistema, sin sobrepasar su capacidad de carga. Sin embargo, esta situación no se suele dar en las sociedades desarrolladas, ya que las ciudades son sistemas abiertos que absorben una gran parte de recursos externos. Los estudios metabólicos urbanos se han llevado a cabo con cierta regularidad, desde que Abel Wolman[10] estableciera una analogía similar al usar una ciudad americana imaginaria, para estimar los flujos de agua, energía y alimentos que se necesitarían para alimentar ese sistema urbano. El análisis posterior de los flujos de energía en otras ciudades, como Hong Kong o Bruselas, confirmaba que alrededor de dos tercios de la demanda urbana se consumían en transporte y en los edificios.

En este capítulo se estudian las variables de la forma urbana que influyen en la eficiencia energética de los edificios. Las correlaciones entre forma y el rendimiento deben establecerse claramente para poder predecir los posibles efectos de las propuestas de planeamiento sobre el metabolismo urbano. Hay dos formas en las cuales la eficiencia de los edificios se ven afectadas por la morfología urbana. El primer nivel tiene que ver con la posición relativa en la ciudad y la climatología urbana. La forma de la ciudad genera diferentes microclimas, lo que puede inducir variaciones térmicas de hasta 10 grados en zonas relativamente próximas. Se ha constatado que la geometría urbana, así como las condiciones climáticas, tienen una fuerte influencia en este fenómeno, conocido como efecto de isla de calor urbano[11] (ICU). El comportamiento dinámico de la ICU se explora e ilustra a través de mapas analíticos de seis ciudades europeas. Se analiza el impacto potencial de la ICU sobre los patrones de consumo de energía en las

10 Wolman, 1965
11 Oke, 1987

A presión social obrigou aos gobernos a actuar, propoñendo avaliacións específicas sobre o impacto no medio ambiente como parte obrigatoria dos plans de desenvolvemento urbano e os proxectos industriais. A conservación dos hábitats naturais e a mitigación das perturbacións nos sistemas ecolóxicos adquiriron gran importancia durante este segundo ciclo de reformulación ambiental. Posteriormente, a crise nas industrias occidentais, que comezaron o seu declive a partir dos anos sesenta , trouxo o desemprego masivo ao corazón das cidades, e inspirou a unha nova axenda no marco do estado do benestar : o desenvolvemento sustentable. As preocupacións sociais e ambientais que se suscitaron nos dous ciclos anteriores se complementaron agora con obxectivos económicos, para completar o triángulo sustentable. A boa forma na cidade actual será, polo tanto, aquela que permita o mantemento do benestar das xeracións presentes e futuras.

Capítulo 4: Enerxía dos edificios e forma urbana. O concepto de satisfacción das necesidades das xeracións presentes e futuras implica unha seria consideración dos recursos dispoñibles e o equilibrio entre o consumo e as taxas de reposición . A analoxía ecolóxica, na cal se comparan as cidades con ecosistemas, utilizouse para crear un método sistemático de avaliación dos fluxos que sustentan as actividades urbanas, incluíndo a enerxía, os alimentos e a auga. Estes fluxos son os que deben manterse dentro de parámetros asumibles polo sistema, sen exceder a súa capacidade de carga. Con todo, esta situación non se adoita dar nas sociedades desenvolvidas, xa que as cidades son sistemas abertos que absorben unha gran parte de recursos externos. Os estudios metabólicos urbanos leváronse a cabo con certa regularidade, desde que Abel Wolman[10] establecese unha analoxía similar ao usar unha cidade americana imaxinaria , para estimar os fluxos de auga, enerxía e alimentos que se necesitarían para alimentar ese sistema urbano. A análise posterior dos fluxos de enerxía noutras cidades, como Hong Kong ou Bruxelas, confirmaba que uns dous terzos da demanda urbana consumíanse en transporte e nos edificios.

Neste capítulo estúdanse as variables da forma urbana que inflúen na eficiencia enerxética dos edificios. As correlacións entre forma e o rendemento deben establecerse claramente para poder predicir os posibles efectos das propostas de planeamento sobre o metabolismo urbano. Hai dúas formas nas cales a eficiencia dos edificios vense afectadas pola morfoloxía urbana. O primeiro nivel ten que ver coa posición relativa na cidade e a climatoloxía urbana. A forma da cidade xera diferentes microclimas, o que pode inducir variacións térmicas de ata 10 grados en zonas relativamente próximas. Constatouse que a xeometría urbana, así como as condicións climáticas, teñen unha forte influencia neste fenómeno, coñecido como efecto de illa de calor urbana[11] (ICU). O comportamento dinámico da ICU explórase e ilustra a través ciudades de Londres y Barcelona, mostrando cómo el mismo edificio, presenta un rendimiento diferente según la zona de la ciudad en la que esté ubicado. La segunda conexión entre forma urbana y la eficiencia de los edificios consiste en la relación simbiótica que cada edificación mantiene con su entorno inmediato. Según Baker y Steemers[12], el entorno urbano puede inducir variaciones de hasta el 100% de la demanda de energía de un edificio. Una densidad elevada pueden repercutir en un menor acceso solar o una ventilación inadecuada, mientras que los desarrollos de baja densidad están más expuestos a las condiciones climáticas. Los aspectos que determinan la eficiencia del edificio son analizados en relación con parámetros urbanísticos. Una matriz sintética resume todas las conexiones identificadas entre forma urbana y la demanda de energía de los edificios, indicando la existencia o no de correlación, su grado y su sentido.

Capítulo 5: Forma Urbana y el impacto de la movilidad generada. En este capítulo, el foco se desplaza al análisis de la movilidad y su conexión con la estructura espacial de la ciudad, como segundo factor más importante en el metabolismo urbano. Se parte de la introducción de los principios y conceptos básicos para entender los patrones de desplazamientos urbanos, sus impactos y los principales estudios realizados hasta la fecha. En los siguientes párrafos se discuten, con gran detalle, los modelos clásicos de transporte, sus métodos y componentes. La segunda parte se centra en la incidencia de la forma urbana en la generación de movilidad, un tema que ha sido estudiado profusamente, pero sigue siendo controvertido. Se aborda también el tema de la densidad, variable que ha sido a menudo identificada como un elemento moderador de la necesidad de viajar, sobre todo después del estudio comparativo realizado por Newman y Kenworthy en unas 300 ciudades[13]. Los argumentos y evidencias a favor y en contra de esta teoría se recogen y analizan desde una perspectiva crítica. Finalmente, se lleva a cabo un meta -análisis para comparar los resultados de una selección de estudios sobre ciudades europeas. Las conexiones más consistentes se representan gráficamente en una nueva matriz sintética.

Sección 2: Análisis y Aplicación. La segunda sección de la primera parte trata de dar respuesta a un vacío identificado en los instrumentos analíticos disponibles. La investigación de esta tesis requiere herramientas para evaluar el comportamiento energético a escala urbana. Sin embargo, estas no existen o no están disponibles. Se testearon algunos programas que se encontraban en desarrollo, pero ninguno de ellos se consideró apropiado para llevar a cabo análisis a escala de ciudad. La solución consistió en el desarrollo de un método y una herramienta originales, creados específicamente como parte de la tesis.

12 Baker & Steemers, 2000

13 Newman & Kenworthy, 1989

de mapas analíticos de seis cidades europeas. Analízase el impacto potencial da ICU sobre os patróns de consumo de enerxía nas cidades de Londres e Barcelona, mostrando como o mesmo edificio, presenta un rendemento diferente segundo a zona da cidade na que estea situado. A segunda conexión entre forma urbana e a eficiencia dos edificios consiste na relación simbiótica que cada edificación mantén coa súa contorna inmediata. Segundo Baker e Steemers[12], o contexto urbano pode inducir variacións de ata o 100% da demanda de enerxía dun edificio. Unha densidade elevada pode repercutir nun menor acceso solar ou unha ventilación inadecuada, mentres que os desenvolvementos de baixa densidade están máis expostos ás condicións climáticas. Os aspectos que determinan a eficiencia do edificio son analizados en relación con parámetros urbanísticos. Unha matriz sintética resume todas as conexións identificadas entre forma urbana e a demanda de enerxía dos edificios, indicando a existencia ou non de correlación, o seu grado e o seu sentido.

Capítulo 5: Forma Urbana e o impacto da mobilidade xerada. Neste capítulo, o foco desprázase á análise da mobilidade e a súa conexión coa estrutura espacial da cidade, como segundo factor máis importante no metabolismo urbano. Se parte da introdución dos principios e conceptos básicos para entender os patróns de desprazamentos urbanos, os seus impactos e os principais estudos realizados ata agora. Nos seguintes parágrafos discútense, con gran detalle, os modelos clásicos de transporte, os seus métodos e compoñentes. A segunda parte céntrase na incidencia da forma urbana na xeración de mobilidade, un tema que foi estudado profusamente, pero segue sendo controvertido. Abórdase tamén o tema da densidade, variable que foi a miúdo identificada como un elemento moderador da necesidade de viaxar, sobre todo despois do estudo comparativo realizado por Newman e Kenworthy nunhas 300 cidades[13]. Os argumentos e evidencias a favor e en contra desta teoría recóllense e analizanse desde unha perspectiva crítica. Finalmente, lévase a cabo unha meta -análise para comparar os resultados dunha selección de estudos sobre cidades europeas. As conexións máis consistentes represéntanse graficamente nunha nova matriz sintética.

Sección 2: Análise e Aplicación. A segunda sección da primeira parte trata de dar resposta a un baleiro identificado nos instrumentos analíticos dispoñibles. A investigación desta tese require ferramentas para avaliar o comportamento enerxético a escala urbana. Con todo, estas non existen ou non están dispoñibles. Se testaron algúns programas que se atopaban en desenvolvemento, pero ningún deles considerouse apropiado para levar a cabo unha análise a escala de cidade. A solución consistiu no desenvolvemento dun método e unha ferramenta orixinais, creados especificamente como parte da tese.

Capítulo 6: Un Modelo de Análisis de Energía y Forma Urbana. En este capítulo se explica la concepción y el desarrollo del Urban Energy Index (UEI), un modelo y aplicación para realizar cálculos rápidos sobre la potencial demanda de calefacción, iluminación y refrigeración en cinco tipos de edificios (residencial, comercial, oficinas, industrial y equipamientos), basado en un análisis de la morfología urbana. El desarrollo de una herramienta a escala urbana implica que muchas variables a nivel de edificio deben pasar a un segundo plano. Dado que ya existe un sólido conocimiento sobre los efectos térmicos derivados de los niveles de aislamiento, tipo y dimensión de carpinterías, etc... Estos parámetros se mantienen constantes con el fin de centrarse única y exclusivamente en variables de la forma urbana. El capítulo comienza con un análisis detallado de los antecedentes que inspiraron el modelo. La facilidad de uso y rapidez en el cálculo fueron objetivos fundamentales. Una estructura consistente y un número reducido de parámetros permiten mantener el control sobre el modelo y las presunciones realizadas. El Urban Energy Index utiliza la edificabilidad (m^2construidos/m^2suelo) la ocupación de suelo (superficie de suelo ocupada) y la compacidad como datos principales de cálculo. La hipótesis para construir el modelo asume que la combinación de estas variables contiene información suficiente para realizar estimaciones significativas del comportamiento energético en grandes áreas urbanas.

La discusión sobre el contexto teórico y las conexiones con la morfología urbana clásica precede a la descripción de los parámetros del modelo , que se dividen en parámetros básicos (edificabilidad, ocupación del suelo y compacidad) , los parámetros por defecto (orientación , altura de planta, proporción de ventanas , tipo de construcción, capacidad térmica y albedo) y parámetros de contexto (zona climática , latitud , orientación de los principales ejes urbanos , usos del suelo y el tipo de construcción predominante) . El modelo matemático y los principios físicos manejados en los cálculos se exponen en las siguientes páginas. La fase clave de esta metodología radica en la simplificación de la morfología urbana, que reduce la trama real a una malla virtual, conservando los parámetros característicos básicos. La preservación de esos valores, que es fundamental para llevar a cabo estimaciones significativas, se demuestra por medio de relaciones matemáticas.

La prueba y validación del modelo es un proceso laborioso en el que se compararon más de dos mil resultados. Veintiocho muestras urbanas fueron seleccionados en cinco ciudades europeas pertenecientes a diferentes zonas climáticas (Madrid, Barcelona, París, Londres y Berlín). Se uso Climatelite como herramienta de referencia para la validación. Se basa en el modelo LT, que ha sido integrado en una interfaz gráfica en la que la geometría urbana se dibuja como en una herramienta tipo CAD. La validación consistió

Capítulo 6: Un Modelo de Análise de Enerxía e Forma Urbana. Neste capítulo explícase la concepción e o desenvolvemento do Urban Energy Index (UEI), un modelo e aplicación para realizar cálculos rápidos sobre a potencial demanda de calefacción, iluminación e refrixeración en cinco tipos de edificios (residencial, comercial, oficinas, industrial e equipamentos), baseado na análise da morfoloxía urbana. O desenvolvemento dunha ferramenta a escala urbana implica que moitas variables a nivel de edificio deben pasar a un segundo plano. Dado que xa existe un sólido coñecemento sobre os efectos térmicos derivados dos niveis de illamento, tipo e dimensión de carpinterías, etc... Estes parámetros mantéñense constantes co fin de centrarse única e exclusivamente en variables da forma urbana. O capítulo comeza cunha análise detallada dos antecedentes que inspiraron o modelo. A facilidade de uso e rapidez no cálculo foron obxectivos fundamentais. Unha estrutura consistente e un número reducido de parámetros permiten manter o control sobre o modelo e as presuncións realizadas. O Urban Energy Index utiliza a edificabilidade (m^2 construídos/ m^2 solo) a ocupación de solo (superficie de solo ocupada) e a compactidade como datos principais de cálculo . A hipótese para construír o modelo asume que a combinación destas variables contén información suficiente para realizar estimacións significativas do comportamento enerxético en grandes áreas urbanas.

A discusión sobre o contexto teórico e as conexións coa morfoloxía urbana clásica precede á descrición dos parámetros do modelo , que se dividen en parámetros básicos (edificabilidade, ocupación do solo e compactidade) , os parámetros por defecto (orientación , altura de planta, proporción de fiestras , tipo de construción, capacidade térmica e albedo) e parámetros de contexto (zona climática , latitude , orientación dos principais eixes urbanos , usos do solo e o tipo de construción predominante) . O modelo matemático e os principios físicos manexados nos cálculos expóñense nas seguintes páxinas. A fase crave desta metodoloxía radica na simplificación da morfoloxía urbana, que reduce a trama real a unha malla virtual, conservando os parámetros característicos básicos. A preservación deses valores, que é fundamental para levar a cabo estimacións significativas, demóstrase por medio de relacións matemáticas.

A proba e validación do modelo é un proceso laborioso no que se compararon máis de dous mil resultados. Vinte e oito mostras urbanas foron seleccionados en cinco cidades europeas pertencentes a diferentes zonas climáticas (Madrid, Barcelona, París, Londres e Berlín). Usouse Climatelite como ferramenta de referencia para a validación. Baséase no modelo LT, que foi integrado nunha interface gráfica na que a xeometría urbana debúxase como nunha ferramenta tipo CAD. A validación consistiu en tres pasos. En primeiro lugar, avaliouse a eficacia da malla virtual para representar a forma urbana real. En segundo lugar, comparáronse os resultados en tres pasos. En primer lugar, se evaluó la eficacia de la malla virtual para representar la forma urbana real. En segundo lugar, se compararon los resultados obtenidos con el UEI con los resultados de modelos Climatelite simplificados (es decir, la misma malla virtual fue modelada en Climatelite). La prueba final consistió en la comparación entre el modelo UEI y los resultados de modelo detallado en Climatelite (es decir, la geometría urbana dibujada edificio a edificio). Los resultados mostraron una correlación general de r^2=0.75 , con una correspondencia más fuerte en tipologías residenciales y cargas de calefacción , mientras que los valores más débiles se corresponden con cargas de iluminación en edificios comerciales y de oficinas.

En la segunda parte de este capítulo se utilizan los resultados de las simulaciones llevadas a cabo como parte del proceso de validación para realizar un análisis tipológico y paramétrico de la forma urbana. El objetivo es doble: por un lado, evaluar la influencia de la densidad edificatoria, la ocupación del suelo y la compacidad en la demanda energética de los edificios y, por otro lado, probar la aplicabilidad de la herramienta. Uno de los hallazgos relevantes consistió en la identificación de debilidades en el análisis paramétrico. Cuando los parámetros urbanos se evalúan por separado, todos los parámetros, excepto aquel que es evaluado permanecerán constantes. Sin embargo, esto se corresponde necesariamente con la realidad, ya que pueden existir relaciones de interdependencia entre variables. Estos se analizan y explican mediante ejemplos, demostrando que el análisis tipológico presenta una mejor descripción de los patrones reales.

Como los resultados del análisis paramétrico no eran suficientemente concluyentes para poder establecer unas pautas generales, la herramienta UEI fue desarrollada en tres formatos diferentes para facilitar las evaluaciones a medida.:

- **Formato hoja de cálculo**, ofrece los resultados más precisos al tiempo que permite una gran flexibilidad.
- **Diagramas regionales,** en los que la energía se puede calcular de forma simple mediante un gráfico específico para cada tipo y zona climática
- **Modelo integrados en SIG**, permite ampliar las capacidades de la herramienta, mejorar la visualización y facilitar la medición automática de parámetros

Parte 2: Investigación Aplicada. La segunda parte de la tesis adopta un enfoque más práctico. Tras aclarar los aspectos y conceptos teóricos, esta parte de la discusión se dedica al análisis de casos reales. Londres y Barcelona fueron seleccionados como ámbitos de estudio porque:

- Representan ejemplos de formas urbanas opuestas: compacidad y dispersión. Esta diferencia se utiliza para probar cómo las estrategias espaciales similares tienen un impacto diferente dependiendo de las condiciones

obtidos co UEI cos resultados de modelos Climatelite simplificados (é dicir, a mesma malla virtual foi modelada en Climatelite). A proba final consistiu na comparación entre o modelo UEI e os resultados de modelo detallado en Climatelite (é dicir, a xeometría urbana debuxada edificio a edificio). Os resultados mostraron unha correlación xeral de r^2=0.75 , cunha correspondencia máis forte en tipoloxías residenciais e cargas de calefacción , mentres que os valores máis débiles correspóndense con cargas de iluminación en edificios comerciais e de oficinas.

Na segunda parte deste capítulo utilízanse os resultados das simulacións levadas a cabo como parte do proceso de validación para realizar unha análise tipolóxica e paramétrica da forma urbana. O obxectivo é dobre: por unha banda, avaliar a influencia da densidade da edificación, a ocupación do solo e a compactidade na demanda enerxética dos edificios e, doutra banda, probar a aplicabilidade da ferramenta. Un dos achados relevantes consistiu na identificación de debilidades na análise paramétrico. Cando os parámetros urbanos se avalían por separado, todos os parámetros, excepto aquel que é avaliado permanecerán constantes. Con todo, isto no se corresponde necesariamente coa realidade, xa que poden existir relacións de interdependencia entre variables. Isto analízase e explicase mediante exemplos, demostrando que a análise tipolóxica presenta unha mellor descrición dos patróns reais.

Coma os resultados da análise paramétrica non eran suficientemente concluíntes para poder establecer unhas pautas xerais, a ferramenta UEI foi desenvolvida en tres formatos diferentes para facilitar as avaliacións a medida. Os potenciais usuarios poderían atopar o formato máis apto para cada situación:

- **Formato folla de cálculo**, ofrece os resultados máis precisos á vez que permite unha gran flexibilidade.
- **Diagramas rexionais,** nos que a enerxía pódese calcular de forma simple mediante un gráfico específico para cada tipo e zona climática
- **Modelo integrados en SIX** , permite ampliar as capacidades da ferramenta, mellorar a visualización e facilitar a medición automática dos parámetros de entrada.

Parte 2: Investigación Aplicada. A segunda parte da tese adopta un enfoque máis práctico. Tras aclarar os aspectos e conceptos teóricos, esta parte da discusión dedícase á análise de casos reais. Londres e Barcelona foron seleccionados como ámbitos de estudo polas seguintes razóns:

- Representan exemplos de formas urbanas opostas: compactidade e dispersión. Esta diferenza utilízase para probar como as estratexias espaciais similares teñen un impacto diferente dependendo das condicións existentes. Por exemplo, unha hipótese da investigación sostén que existentes. Por ejemplo, una hipótesis de la investigación sostiene que la densificación tendría un mayor efecto en Londres que en Barcelona, ya que esta última es ya una ciudad de densidad elevada, con poco recorrido.

- Ambas ciudades han emprendido importantes proyectos de regeneración en sus áreas centrales que conllevaron a una transformación parcial de su forma urbana. Esto proporciona un marco real para un debate que normalmente se queda en la indefinición abstracta. Las dificultades y consecuencias derivadas de la densificación del centro se ejemplifican con los dos casos.
- Existen datos abundantes sobre las dos ciudades y los distritos regenerados.
- Ninguno de los casos de estudio se ha destacado como un modelo de intervención urbana sostenible. Sin embargo, esto es visto como un valor positivo ya que, por un lado, permite una visión limpia y sin distorsiones y, por otro lado, los aprendizaje extraídos de experiencias de planificación urbana reales son más fáciles de generalizar que cuando se trata de proyectos especiales que responden a condiciones muy específicas.

Sección 3: Casos de estudio. En la primera sección de la segunda parte se analiza la evolución urbana las transformaciones más recientes en las dos ciudades estudiadas. Cada período se vincula a su forma urbana característica, tanto a escala regional como intraurbana. La evolución metropolitana se retrata a través de mapas en los que se resalta el progresivo avance urbanizador. Las transformaciones del tejido se identifican por las huellas dejadas en la estructura espacial actual. Las tipologías urbanas no son espontáneas, sino que responden decisiones tomadas en momentos puntuales y por razones específicas. El desarrollo histórico de la forma urbana ayuda a entender los procesos que indujeron cada tipología formal. La diferencias en la geografía y el contexto social y político entre Barcelona y Londres se tradujeron en su forma espacial. La comprensión de los acontecimientos históricos se utiliza para reconocer las tipologías predominantes en la ciudad post-industrial, lo cual ofrece información sobre su comportamiento, y permite anticipar su evolución futura.

Ambas ciudades han experimentado un proceso de descentralización y la decadencia de sus distritos industriales tradicionales durante la segunda parte del siglo veinte. La regeneración de estas zonas supuso una reversión en los patrones de urbanización, centrando la atención de nuevo en la ciudad.

Capítulo 7: La formación de una ciudad dispersa: Londres. En este capítulo se analiza la evolución urbana de Londres, desde la época romana hasta la actualidad. La formación de Londres estuvo determinada por su posición estratégica en el punto de cruce más externo del estuario del Támesis. Aunque es sede de la Corte Real, Londres ha sido

o incremento da densidade tería un maior efecto en Londres que en Barcelona, xa que esta última é xa unha cidade de densidade elevada, con pouco percorrido.

- Ambas cidades emprenderon importantes proxectos de rexeneración nas súas áreas centrais que deron lugar a unha transformación parcial da súa forma urbana. Isto proporciona un marco real para un debate que normalmente quédase na indefinición abstracta. As dificultades e consecuencias derivadas da densidade son exemplificadas cos dous casos.
- Existen datos abundantes sobre as dúas cidades e os distritos rexenerados.
- Ningún dos casos de estudo destacouse como un modelo de intervención urbana sustentable. Con todo, isto é visto como un valor positivo xa que, por unha banda, permite unha visión limpa e sen distorsións e, doutra banda, as aprendizaxes extraídas de experiencias de planificación urbana reais son máis fáciles de xeneralizar que cando se trata de proxectos especiais que responden a condicións moi específicas.

Sección 3: Casos de estudo. Na primeira sección da segunda parte analízase a evolución urbana e as transformacións máis recentes nas dúas cidades estudadas. Cada período vincúlase á súa forma urbana característica, tanto a escala rexional como intraurbana. A evolución metropolitana retrátase a través de mapas nos que se resalta o progresivo avance da urbanización. As transformacións do tecido identifícanse polas pegadas deixadas na estrutura espacial actual. As tipoloxías urbanas non son espontáneas, senón que responden decisións tomadas en momentos puntuais e por razóns específicas. O desenvolvemento histórico da forma urbana axuda a entender os procesos que induciron cada tipoloxía formal. As diferenzas na xeografía e o contexto social e político entre Barcelona e Londres traducíronse na súa forma espacial. A comprensión dos acontecementos históricos utilízase para recoñecer as tipoloxías predominantes na cidade post-industrial, o cal ofrece información sobre o seu comportamento, e permite anticipar a súa evolución futura.

Ambas cidades experimentaron un proceso de descentralización e a decadencia dos seus distritos industriais tradicionais durante a segunda parte do século vinte. A rexeneración destas zonas supuxo unha reversión nos patróns de urbanización, centrando a atención de novo na cidade.

Capítulo 7: A formación dunha cidade dispersa: Londres. Neste capítulo analízase a evolución urbana de Londres, desde a época romana ata a actualidade. A formación de Londres estivo determinada pola súa posición estratéxica no punto de cruzamento máis externo do estuario do Támesis. Aínda que é sé da Corte Real, Londres foi unha cidade de comerciantes, un carácter que se mantén aínda vixente. O capítulo desenreda o aparentemente continuo urbano para una ciudad de comerciantes, un carácter que se mantiene todavía vigente. El capítulo desenreda el aparentemente continuo urbano para conocer la estructura urbana subyacente de Londres, haciendo uso de abundante material gráfico, gran parte de la cual ha sido elaborado específicamente.

Capítulo 8: La densificación en una ciudad post-industrial dispersa: los Docklands de Londres. El proceso de remodelación de los antiguos muelles de Londres ha sido uno de los mayores proyectos de regeneración en Europa. La posición de Londres como centro del Imperio Británico requería un gran puerto para manejar el intenso comercio con las colonias. Este capítulo comienza con la explicación de cómo este puerto adquirió su configuración final, mediante un proceso de especulación y competencia caníbal, que acarreó una incapacidad para adaptarse a cambios tecnológicos. La decadencia del puerto barrió el sustento de las comunidades locales, definidos por baja cualificación y alta dependencia de las actividades marítimas. El proceso de transformación de los Docklands, de centro industrial a distrito financiero tuvo que afrontar el equilibrio entre las necesidades de la población local con las fuerzas de desarrollo inmobiliario. Las estrategias y planes para llevar a cabo la regeneración y su aplicación real se examinan en la parte principal del capítulo. Una serie de planos sintetizan las intervenciones espaciales en las diferentes zonas de Docklands, resumiendo las principales cifras de la operación y el resultado final.

Capítulo 9: El paradigma de la ciudad compacta: Barcelona. La evolución de Barcelona presenta paralelismos y contrastes con Londres. Hasta el siglo dieciocho, los patrones de urbanización son similares a muchas otras ciudades europeas, con sucesivas ampliaciones en cuanto la densificación dentro de las murallas se hacía insoportable. A principios de ese siglo, esta tendencia se vio interrumpida por el control militar de la ciudad en represalia a su apoyo a los monarcas franceses durante la Guerra de Sucesión Española. El recinto medieval se masificó por la densificación progresiva del tejido y la incapacidad de crecer más allá de la muralla. Cuando, más de un siglo después, las murallas pudieron ser finalmente demolidas, se pudo por fin diseñar un ensanche sobre el suelo del plano circundante. A mediados del siglo veinte, la malla de Cerdà había llegado ya a las colinas de Collserola, una barrera geográfica que supuso un nuevo freno a la expansión. En este capítulo se presenta la formación de Barcelona como una ciudad compacta, las razones que llevaron a su forma actual y las tipologías urbanas predominantes que surgieron de ella. Al igual que en los capítulos anteriores, el material gráfico es un instrumento clave para llevar a cabo el análisis de la evolución de la forma urbana.

Capítulo 10: La densificación en una ciudad Post-Industrial compacta: Del Poblenou al 22 @. Poblenou es un barrio industrial se originó en el siglo diecinueve con

coñecer a estrutura urbana subxacente de Londres, facendo uso de abundante material gráfico, gran parte do cal foi elaborado especificamente.

Capítulo 8: A densificación nunha cidade post-industrial dispersa: os Docklands de Londres. O proceso de remodelación dos antigos peiraos de Londres foi un dos maiores proxectos de rexeneración en Europa. A posición de Londres como centro do Imperio Británico requiría un gran porto para manexar o intenso comercio coas colonias. Este capítulo comeza coa explicación de como este porto adquiriu a súa configuración final, mediante un proceso de especulación e competencia caníbal, que carrexou unha incapacidade para adaptarse a cambios tecnolóxicos. A decadencia do porto varreu o sustento das comunidades locais, definidos por unha baixa cualificación e alta dependencia das actividades marítimas. O proceso de transformación dos Docklands, de centro industrial a distrito financeiro tivo que afrontar o equilibrio entre as necesidades da poboación local coas forzas de desenvolvemento inmobiliario. As estratexias e plans para levar a cabo a rexeneración e a súa aplicación real examínanse na parte principal do capítulo. Unha serie de planos sintetizan as intervencións espaciais nas diferentes zonas dos Docklands, resumindo as principais cifras da operación e o resultado final.

Capítulo 9: O paradigma da cidade compacta: Barcelona. A evolución de Barcelona presenta paralelismos e contrastes con Londres. Ata o século dezaoito, os patróns de urbanización son similares a moitas outras cidades europeas, con sucesivas ampliacións en canto a densidade dentro das murallas facíase insoportable. A principios dese século, esta tendencia viuse interrompida polo control militar da cidade en represalia ao seu apoio aos monarcas franceses durante a Guerra de Sucesión Española. O recinto medieval masificouse pola densificación progresiva do tecido e a incapacidade de crecer máis aló da muralla. Cando, máis dun século despois, as murallas puideron ser finalmente demolidas, púidose por fin deseñar un ensanche sobre o solo do plano circundante. A mediados do século vinte, a malla de Cerdà chegara xa aos outeiros da Collserola, unha barreira xeográfica que supuxo un novo freo á expansión. Neste capítulo preséntase a formación de Barcelona como unha cidade compacta, as razóns que levaron á súa forma actual e as tipoloxías urbanas predominantes que xurdiron dela. Do mesmo xeito que nos capítulos anteriores, o material gráfico é un instrumento crave para levar a cabo a análise da evolución da forma urbana.

Capítulo 10: A densificación dunha cidade Post-Industrial compacta: Do Poblenou ao 22 @. Poblenou é un barrio industrial que se orixinou no século dezanove cunha lóxica urbana propia e que foi absorbido pola retícula de Cerdà a principios do vinte. O seu desenvolvemento como zona industrial e loxística produciuse nunhas condicións de baixa calidade urbana, propiciando a aparición chabolas una lógica urbana propia y que fue absorbido por la retícula de Cerdà a principios del veinte. Su desarrollo como zona industrial y logística se produjo en unas condiciones de baja calidad urbana, propiciando la aparición de pequeñas chabolas de familias de clase trabajadora en su periferia. Este capítulo analiza las diferentes etapas de la regeneración de esta zona, desde el período pre -olímpico hasta la actualidad. Al igual que en los Docklands, este proceso presenta una gran variedad de instrumentos de planificación, conceptos y estrategias aplicadas para transformar una parte consolidada de la trama urbana , en la cual aún operaban pequeñas empresas , vivían numerosas familias y se llevaban a cabo eventos culturales. En este capítulo se informa, de forma descriptiva y analítica, la secuencia de acontecimientos, el contexto en el que se tomaron las decisiones y las consecuencias en la estructura espacial y sobre las comunidades locales de la transformación del barrio del Poblenou.

Sección 4: Análisis Comparativo. La última sección consiste en un análisis metabólico comparativo de Londres y Barcelona, basado en las tipologías urbanas y la forma metropolitana. En él se resumen los conceptos y las herramientas desarrolladas en la tesis, aplicándolos sobre los casos de estudio. El objetivo es dar respuesta a las hipótesis de partida, planteando postulados altamente especulativos con el fin de proporcionar evidencias sobre la evolución futura y la eficiencia energética de las ciudades.

Capítulo 11: Análisis comparativo y evaluación del comportamiento energético. Los argumentos para definir una forma urbana sostenible varían desde la firme de defensa de la densidad como estrategia para reducir las emisiones de carbono a su opuesto, la creación de comunidades auto -suficientes en un paisaje eminentemente rural. En este capítulo se analizan los casos de estudio para proporcionar una referencia global sobre las magnitudes y consecuencias de las transformaciones urbanas, tanto en términos de comportamiento cuantitativo como en impactos social. Sólo de este modo, será posible establecer una evaluación basada en la combinación de evidencias objetivas y el juicio racional. En esencia, la evaluación comparativa entre Londres y Barcelona tiene como objetivo responder a las siguientes preguntas:

- ¿Cuál es la magnitud del potencial ahorro energético derivado de la compactación urbana?
- ¿Cuáles son los efectos colaterales de la densificación de áreas urbanas consolidadas?
- ¿Justifican los potenciales beneficios los posibles efectos colaterales?
- ¿Existe una alternativa que puede ofrecer beneficios similares sin esos efectos colaterales?

La investigación posterior combina observaciones empíricas con el análisis especulativo para explorar

na súa periferia. Este capítulo analiza as diferentes etapas da rexeneración desta zona, desde o período pre -olímpico ata a actualidade. Do mesmo xeito que nos Docklands, este proceso presenta unha gran variedade de instrumentos de planificación, conceptos e estratexias aplicadas para transformar unha parte consolidada da trama urbana , na cal aínda operaban pequenas empresas , vivían numerosas familias e levábanse a cabo eventos culturais. Neste capítulo infórmase, de forma descritiva e analítica, sobre a secuencia de acontecementos, o contexto no que se tomaron as decisións e as consecuencias na estrutura espacial e sobre as comunidades locais da transformación do barrio do Poblenou.

Sección 4: Análise Comparativo. A última sección consiste nunha análise metabólica comparativa de Londres e Barcelona, baseado nas tipoloxías urbanas e a forma metropolitana. Nel resúmense os conceptos e as ferramentas desenvolvidas na tese, aplicándoos sobre os casos de estudo. O obxectivo é dar resposta a as hipótese de partida, prantexando postulados altamente especulativos co fin de proporcionar evidencias sobre a evolución futura e a eficiencia enerxética das cidades.

Capítulo 11: Análise comparativo e avaliación do comportamento enerxético. Os argumentos para definir unha forma urbana sustentable varían desde a firme de defensa da densidade como estratexia para reducir as emisións de carbono ao seu oposto, a creación de comunidades auto -suficientes nunha paisaxe eminentemente rural. Neste capítulo analízanse os casos de estudo para proporcionar unha referencia global sobre as magnitudes e consecuencias das transformacións urbanas, tanto en termos de comportamento cuantitativo como en impacto social. Só deste xeito, será posible establecer unha avaliación baseada na combinación de evidencias obxectivas e o xuízo racional. En esencia, a avaliación comparativa entre Londres e Barcelona ten como obxectivo responder ás seguintes preguntas:

- ¿Cal é a magnitude do potencial aforro enerxético derivado da compactidade urbana?
- ¿Cales son os efectos colaterais do incremento da densidade en áreas urbanas consolidadas?
- ¿Xustifican os potenciais beneficios os posibles efectos colaterais?
- ¿Existe unha alternativa que pode ofrecer beneficios similares sen eses efectos colaterais?

A investigación posterior combina observacións empíricas coa análise especulativo para explorar as consecuencias de políticas urbanas de compactidade en oposición á continuación das tendencias descentralizadoras actuais. A demanda enerxética per cápita estimada é a variable clave para comparar diferentes escenarios. A enerxía destinada a transporte persoal e calefacción doméstica son os factores específicos cuxas variacións se calculan en relación a las consecuencias de políticas urbanas de compacidad en oposición a la continuación de las tendencias descentralizadoras actuales. La demanda energética per cápita estimada es la variable clave para comparar diferentes escenarios. La energía destinada a transporte personal y calefacción doméstica son los factores específicos cuyas variaciones se calculan en relación a diferentes formas urbanas. El análisis comparativo consiste en dos etapas:

- La primera etapa se basó en la observación detallada de los patrones existentes. Se parte de datos contrastados para realizar un análisis de los flujos de energía en la estructura urbana actual de Londres y Barcelona
- En la segunda etapa del análisis, se elaboraron modelos urbanos sobre la base de los resultados de la fase anterior. Estos modelos sirven para representar escenarios hipotéticos de la evolución futura de Londres y Barcelona, en función de su estructura actual y asumiendo grados alternativos de compactación o expansión alternativamente. Por último, se realizó una estimación de la demanda de energía per cápita para cada escenario, utilizando las herramientas y métodos desarrollados en los capítulos anteriores

diferentes formas urbanas. A análise comparativo consiste en dúas etapas:

- A primeira etapa baseouse en a observación detallada dos patróns existentes. Se parte de datos contrastados para realizar unha análise dos fluxos de enerxía na estrutura urbana actual de Londres e Barcelona
- Na segunda etapa da análise, elaboráronse modelos urbanos sobre a base dos resultados da fase anterior. Estes modelos serven para representar escenarios hipotéticos da evolución futura de Londres e Barcelona, en función da súa estrutura actual e asumindo grados alternativos de compactidade ou expansión alternativamente. Para rematar, realizouse unha estimación da demanda de enerxía per cápita para cada escenario, utilizando as ferramentas e métodos desenvolvidos nos capítulos anteriores.

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